WRINKLES IN PRACTICAL NAVIGATION.

CAPTAIN LECKY

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Wheeler Photo. W. L. Colls Ph. Sc.

WRINKLES

IN

PRACTICAL NAVIGATION

BY

S. T. S. LECKY, MASTER MARINER,

COMMANDER, R.N.R., F.R.A.S., F.R.G.S., Etc.

(LATE HIS MAJESTY'S INDIAN NAVY).

Extra Master. Passed in Steam, Compass Adjustment, &c.

Younger Brother of the Trinity House.

Marine Superintendent of the Great Western Railway.

Author of "The Danger Angle and Off-Shore Distance Tables," and of "Lecky's General Utility Tables."

NINETEENTH EDITION, REVISED AND ENLARGED

BY

WILLIAM ALLINGHAM,

(NAUTICAL ASSISTANT, METEOROLOGICAL OFFICE).

First Class Honours—Navigation. Prizeman—Political Economy

Author of "A Manual of Marine Meteorology,"

"Weather Signs and how to read them; For use at Sea," Etc.

WITH 136 ILLUSTRATIONS AND PLATES.

LONDON

GEORGE PHILIP & SON, LTD., 32 FLEET STREET

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D. VAN NOSTRAND COMPANY

NEW YORK

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TO

THE RT. HON. LORD BRASSEY, K.C.B.,

WHOSE WELL-KNOWN INTEREST IN THE SCIENCE OF NAVIGATION,
AS WELL AS PERSONAL COURAGE AND NAUTICAL SKILL,
WERE SO WELL ILLUSTRATED BY HIS

CIRCUMNAVIGATION OF THE GLOBE

IN COMMAND OF HIS OWN YACHT,

THIS VOLUME,

BY ONE WHO HAD THE PRIVILEGE OF A PLACE IN THE FAMOUS

"SUNBEAM,"

DURING A PORTION OF HER ADVENTUROUS VOYAGE,

IS RESPECTFULLY AND GRATEFULLY INSCRIBED.

PUBLISHERS' NOTE.

In issuing the Nineteenth Edition of "*Wrinkles*," the Publishers wish to draw attention to the fact that it contains numerous important alterations and additions, which it is believed will still further increase its value to practical Seamen.

An entirely new Chapter (Part II. XVA), entitled "New Meteorological Measures for Old," has been included, together with four Appendices dealing with the following subjects: 1. Substitute for Horizon. 2. Gyroscopic Compasses. 3. The Moon an Auxiliary. 4. Chronometers: Use and Abuse.

February, 1917.

PREFACE TO THE FIFTEENTH EDITION.

FOR some years I was honoured with the close personal friendship of the late Captain Lecky, and, quite naturally, the future of "*Wrinkles*" not infrequently came up for close consideration. All too soon, however, my friend and master was compelled by failing health to seek a respite from his labours under the sunnier sky of Las Palmas, and there death put a period to his adventurous career and strenuous life. A sterling seaman of the salt-water school, modern to his finger-tips, and a staunch friend—one always more willing to walk with Sir Knight than with Sir Priest—Captain Lecky's memory will long be cherished by seamen of every nation. His comprehensive intellect, his ripeness of judgment, his meditative mind, and his manly independence, are clearly displayed in "*Wrinkles*," which was to him a labour of love, and concerning which he might rightly have written, in the words of Horace on a similar occasion, "*non omnis moriar: multaque pars mei vitabit Libitinam.*"

It has devolved upon me to revise "*Wrinkles*" for this fifteenth edition, and in the task I have been greatly helped by a knowledge of Captain Lecky's methods and his aims with respect to the book. Something new and true has been added; some of the chapters have been re-written, consequent on changes which could not have been foreseen by the author; and neither time nor trouble has been spared to bring the book right up to date. It is therefore anticipated, with some degree of confidence, that "*Wrinkles*" will at least maintain the high reputation it has held among the world's navigators ever since the First Edition brought out by Captain Lecky a quarter of a century ago.

Should this belief be justified by results, the Fifteenth Edition of "*Wrinkles*" will serve not less than two purposes: It will continue to "awaken the interest of the student by making the subject attractive, and to train his intelligence by bringing before him whatever is striking, novel, and instructive" in the particular branches of the nautical profession with which it deals; and it will perpetuate the high navigational knowledge, and the capacity for taking pains, which were such marked features of the Author's life.

WILLIAM ALLINGHAM.

AVOCA, GROVE PARK,
DENMARK HILL, LONDON, 1907.

PREFACE TO FIRST EDITION.

THE particular aim of this treatise is to furnish seamen with thoroughly *practical* hints, such as are not found in the ordinary works on Navigation; or, if they do exist, are scattered through so many pages, and so smothered by their surroundings, as to require too much digging out—too many shells to be cracked before arriving at the kernel—a tedious process, which the practical mind recoils from: further, to indicate the shortest and most reliable methods, as well as the instruments and books necessary to enable the Navigator (amateur or professional) to conduct his vessel safely and expeditiously from port to port.

The various nautical instruments are treated of separately, their peculiarities explained, and the errors to which they are liable pointed out, with the best means of remedying them, or of compensating their effects.

The volume contains but little that is claimed as strictly original: it is based upon life-long observation, matter gleaned from the works of men of repute, and information derived from intercourse with shipmates and the cloth generally.

The mass of material at one's disposal renders its clear presentment within a moderate compass somewhat difficult, but great pains have been taken to select only the really essential problems, and, in view of those to whom the work is addressed, to choose the simplest possible language. If the style is thus more familiar than dignified, it is hoped that it may with greater success attract the ear, and rivet the understanding of the nautical reader, thereby awakening and sustaining such an interest in the subject as will be most likely to create mental impressions of a lasting kind. Diagrams accompany many of the examples by way of illustrating and giving prominence to some of the more "important simplicities" of navigation, which are unhappily too often disregarded by reason of their true significance not being understood and appreciated. To this end, also, a free use has been made of capitals, and certain words and sentences are rendered conspicuous by a change of type when it appears advantageous to do so.

If occasionally the reader of quick apprehension is irritated by too great minuteness, he must remember that as far as possible every imaginable question has to be anticipated, and that a single point left unexplained may render useless an otherwise careful description.

Every sailor knows what is meant by a "Wrinkle"; some possess more than others, and in penning the following pages the writer has endeavoured to display his to the best advantage, and place them "cut and dried" at the disposal of such members of the profession as have had a less varied experience than himself, and fewer facilities of acquiring an intimate knowledge of this branch of their business.

Methods have been selected which offer peculiar advantages in the matter of *brevity of solution*. To seamen this is very important, as all know; at the same time *accuracy of the results* has been kept in view, and care taken that the latter quality is not unduly sacrificed to the former.

Rigorous exactness of working—so necessary in the schoolroom —is but seldom required on board ship; it is, therefore, only introduced in the process of rating chronometers, and one or two other instances, where, from the nature of the question, one is absolutely *forced* to deal with minute arithmetical quantities. Very many problems of interest to the scientific Navigator, as well as the discussion of many refinements of correction and reduction—which, neat as they may be in theory, are of little practical value—have been purposely omitted. On the other hand, an endeavour has been made to avoid the slovenly "Rule of thumb," "Rough and ready" principle which has given rise to the saying—somewhat unjust to a good class of seamen—"it is near enough for a collier."

These and other characteristics, it is hoped, may commend the work to the notice and approval of the profession.

It must not be imagined that this book is written in any respect as a *direct* help to the Local Marine Board Examinations; there are plenty of excellent ones published for that express purpose. This has entirely to do, as its name indicates, with every-day navigation on board ship: the reader is supposed, indeed, to be in proud possession of his Master's certificate—if with blue seal so much the better; to have overcome the moonshine terrors of Decimal Arithmetic, and to have some slight knowledge of Plane Trigonometry. If, however, these pages should be read by one who has yet to undergo the ordeal of examination, the writer trusts that the introduction behind the scenes, and the knowledge of first principles thereby acquired, will teach him *to think for himself*, and be of service generally in enabling him to gain the coveted parchment.

To the daring yachtsman, ambitious of personally undertaking the conduct of his white-winged craft to distant parts of the world, and who has already acquired a certain groundwork of navigation, it is hoped that this Manual will present not a few advantages: it will be a sort of nautical finger-post at the junction of many devious paths, which will point out to him the safest way to his destination; and, whilst providing him with sound advice on most of the necessary points, will not distract his attention and waste his time on what, even to the professional, may be regarded as superfluous, or of questionable importance.

Under this last heading comes Marine Surveying—which is, consequently, excluded *in toto* as constituting a distinct study, and one which, in these exact days, can scarcely be said to come within the province of merchant seamen, whatever it may have done in times gone by. If, however, Marine Surveying should be taken up by anyone who has a natural taste for that sort of thing, with leisure and opportunity for indulging it, he should study such books as are devoted *exclusively* to it, since it is a subject more difficult than many at first would suppose. *

In one matter, more especially, the Author would crave the gracious forbearance of the Critic. He wishes it thoroughly understood that not in the least degree does he claim for his present venture what is known as "literary merit." A lad who, at twelve or thirteen, adopts the rough career of a sailor, when more fortunate ones of the same age are only just commencing their education, cannot reasonably be expected in after life to shine as a brilliant star in the literary firmament. It is scarcely consistent with the "eternal fitness of things" that he should. Our Gallic neighbours have a proverb which is in every way applicable—"Chacun son metier, et les vaches sont bien gardées;" which, when freely translated into the nautical language of Britain, reads thus—"The Gunner to his linstock, the Steersman to the wheel, and the Cook to the foresheet."

The book, therefore, is merely a friendly offer of help from one sailor to another—nothing more. Some readers, no doubt, will make it their proud boast that they "clambered in through the hawse-pipes," whilst others will have "entered by the cabin windows." To both the Author is not without hope his "Wrinkles" may prove acceptable, and that, like a "Handy-Billy" clapped

* About the most complete work is "Hydrographical Surveying," by Capt W. Wharton, R.N. It was published by John Murray in 1882. Second edition in 1898.

on to the fall of a "Luff-tackle Purchase," the present book may assist the more powerful ones in pulling the Shipmaster through many of the navigational troubles by which he is often beset.

In conclusion, should Experts complain that they do not find anything novel in this volume, the writer would merely remind them that it was not his intention that they should. The book has been prepared for comparatively young members of the profession; and one of the leading objects has been to elucidate in plain English some of those important elementary principles which the *Savants* have enveloped in such a haze of mystery as to render pursuit hopeless to any but a skilled mathematician.

Comparatively few sailors are good mathematicians, and, in the writer's opinion, it is fortunate that such is the case; for Nature rarely combines the mathematical talent of a Cambridge wrangler with that practical tact, observation of outward things, and readiness on an emergency, so essential to a successful sea Captain, who, curiously enough, is always expected to be as many-sided as the "Admirable Crichton"—at once Sailor, Navigator, Parson, Lawyer, Doctor, and a host of things besides.

The Author has only to add that he has done his best to secure accuracy in the printing of the book, and trusts that few errors of moment will be found to have crept in. He will at all times be thankful to receive corrections and suggestions for the improvement of future editions.

SQUIRE THORNTON STRATFORD LECKY.

LIVERPOOL, *November 1881.*

PREFACE TO THE NINTH EDITION.

ALLAH be praised! "Wrinkles" has successfully withstood that most crucial of all tests—the test of Time. On every sea and in every manner of craft it has been afloat for better than twelve years, and luckily seems to have found favour with 'all sorts and conditions of men.'

On board the schoolships *Conway* of the Mersey, and *Worcester* of the Thames, it has long been included among the prizes bestowed upon the youthful heroes of the moment. With infinite satisfaction it has recently come to my knowledge that even in H.M.S. *Britannia* it is not considered unworthy of a place at similar great festivals. For a book with no pretensions to mix in such goodly company, this is not bad; on the contrary, it is very cheering, and has acted as a stimulus in the production of the present edition.

In view of self-evident facts, it is not stepping over the mark to say that the popularity and wide circulation of "Wrinkles" has very considerably revolutionised the *practice* of navigation. This it has accomplished more particularly by drawing attention to *points of working detail* not previously dealt with by the text-books, these having—as might be expected—invariably treated the subject from a purely academical point of view, and that a trifle ancient of its kind.

Somebody very truthfully lays it down that 'The mastery of the ocean cannot be learnt upon the shore'; and so the many impediments to turning Theory into Practice were not even so much as hinted at, it being perforce ignored by the various learned writers—mostly landsmen more accustomed to streets than straits, shops than ships (no disrespect intended)—that navigation in the safe seclusion of the study, and navigation on board a storm-tossed and danger-beset ship, were two vastly different things. In fact, the young commander, as soon as the pilot uttered his parting benediction, "A pleasant voyage, Captain," and had slipped over the side into his dingy, was left to flounder about as best he could in a veritable sea of difficulties. The mission of "Wrinkles," written by one who has been through the mill in right good earnest, was to go to the rescue and 'stand by' until such time as our young friend felt himself in every sense *Master* of the situation, and able to shift for himself.

Responsibility is a word devoid of meaning to all save those who have to bear it. Do not most Mates think themselves smarter men than the Masters? And yet Masters are all made from Mates!! What is accountable for the change?

Further, in the revision of works on Navigation, the production of new ones, perhaps also to some extent in the Board of Trade *curriculum*, and consequentially in the teaching of the 'Coaches,' "Wrinkles" has undeniably conduced to the discarding of 'played out' methods, and the substitution of others of greater *pliability* and less *ponderosity*. Some of the most capable instructors have not been above taking hints from it, and even *saying* so; whilst sundry opticians in the marine line have been stirred up to modify certain of their instruments, and in several cases to devise others better adapted to the 'Navigation of the Period,' which has become uncommonly rapid—so rapid, that to 'Look slippery' is now the all-pervading motto. The Victorian era may truly be said to form an eventful epoch in the progress of navigation, and no man knoweth the end.

It is no longer the 'stand-off-shore-till-it-clears' navigation of the two-foot rule order; no more 'waiting for slants'; no 'grounding on beef bones. 'Growl you may, but go you must.'

There used to be a fo'k'stle phrase very often heard during the reign of the old 'Black Ball liners,' viz., 'Liverpool on her stern and *bound* to go.' That was when every fellow who could handle pick, pan, and shovel—or at least *thought* he could—was in a state of frenzy to reach the Australian El Dorado: but in this later age of telephones, and telegraphs to the uttermost ends of the earth, craft of nearly every shape and colour—no matter where they hail from—are 'bound to go.' In fact, it is 'Rush' all the time; or, as Jack puts it—'No peace for the wicked.'

As with other branches of science, so also in the seafaring direction, the march of events has brought about many improvements. There is a regular epidemic of inventions; some good, some indifferent, and others so absolutely worthless as to be at once relegated to the limbo of useless rubbish: but all bring grist to the mill of the patent agent, though not necessarily to the inventors. 'It is an ill wind,' &c.

Out of the ruck we have now instruments of beautiful precision, and much greater capabilities than heretofore. It would, however, be wrong to infer that thereby the duties of the navigator had been rendered less arduous, or that he was in any degree being coddled, or 'fed with a spoon'; on the contrary, the demands upon his energy, vigilance, nerve, and endurance, are greater than ever. These refined appliances—the outcome of the skill of the modern mechanician—are simply called into existence by the exigencies of rapid transit. Without them, and without *the right kind of men to use them*, the speed, which costs so enormously, would in a measure be thrown away. A '22-knotter,' costing half a million sterling, and despite triple-expansion engines, swallowing fully 20 tons of coal *per hour*, with perhaps 200 of a 'black squad,' and nearly as many hands in the victualling department, cannot afford to wander at large over the ocean *à la Columbus*. To do so would seriously interfere with the gilt on the gingerbread, and probably permit a less speedy, though more skilful, rival to slip in first. Just fancy the discomfiture of the one, the jubilation of the other, and how the 22-knot engineers would swear! The atmosphere of the mess-room would be perfectly blue with parliamentary language.

Hence the great need, in these highly-pitched competitive times, of the professional knowledge which will keep a vessel's stem pointed *dead straight* for her destination *during every single minute of night and day*. Owners, alive to this fact, are becoming more and more particular in selecting men for command who can do it. It is the same on shore. There are drivers of goods trains, and drivers of express trains; the latter are considered the best men, and entitled to best pay, *and they get it*.

No amount of 'cracking on' or 'firing up' will compensate for bad courses, and eventually having to 'skirmish round' for one's port in thick weather; it is simply misdirected energy of an expensive kind. On the whole, an impetus has been given to everything connected with this branch of the seaman's art, whether in the humble 'tramp,' the gorgeous 'greyhound,' or the persevering 'wind-jammer.' It behoves their respective skippers to rise to the occasion and shew their mettle—not pot-metal.

In the literature of navigation, 'Raper'—probably because written by a seaman understanding seamen's wants—still holds the position of premier epitome. It has recently (1891) been revised in a very judicious manner by that Ancient Mariner and Cunning Pilot, Commander T. A. Hull, R.N., formerly Superintendent of Admiralty Charts. Beyond a few modern necessities, such as a chapter on compasses in iron vessels, the extension of the Traverse Table, and bringing it up to date generally, Captain Hull has shewn his good sense by 'leaving *very* well alone'; so, to the gratification of its devotees, 'Raper' still remains 'Raper.'

Not so with our quondam chum, 'John Norie.' It is no more the same venerated oracle which was conned to destruction in the days of one's apprenticeship, long long ago; for 'Norie' has been almost, if not entirely, rewritten by W. H. Rosser (1889), so well known to London aspirants for Board of Trade parchment. Were it not for the title, one would hardly recognise its re-juvenated pages. Certainly re-modelling was needed, and the new 'Norie' will no doubt continue as popular with a certain set as it was in the now almost pre-historic times when the frigate-built Indiamen of Green, Wigram, Smith, and Dunbar, entered Blackwall docks in all their glory, with yards and gunports squared to a nicety, bunt-jiggers bowsed up for a harbour furl, stun'sail booms rigged out to the mark, hammock-nettings neatly stowed, and a welcoming crowd of both sexes cheering and waving greetings from the pierheads. The sea then had a halo of romance about it, a blue-water flavour, which, alas, is now replaced by cast-iron and mild steel. The romance has been buried in the coal-bunkers.

If one may judge by the differences here and there in the doctrines of the old and new 'Norie,' its painstaking reviser

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has read "Wrinkles" to some purpose, and has taken to heart at least some of its precepts. This tribute from a veteran teacher, silent though it be, is much appreciated.

Inman's excellent Tables have been revised, re-arranged, and enlarged (1888). They are the only nautical ones in which the log. sines, secants, tangents, &c., are given to every 15″ of arc—no inconsiderable advantage to close workers. It is incomprehensible that these fine tables are not better known in the merchant service.

But the gem in its way is *Navigation and Nautical Astronomy*, by Staff-Commander W. R. Martin, of the Royal Naval College (1891). It goes without saying that this is a thoroughly safe guide, and has accordingly been adopted by the Admiralty as the orthodox text-book in the naval service; indeed, it was written expressly for this purpose. The deadly dulness incidental to official text-books in general is, in this case, relieved by copious notes and interesting historical references; but the character of the book is mathematical to a degree somewhat over the heads of the present generation of merchant officers, who, with the exception perhaps of certain *Conway* and *Worcester* boys, and a few others with a natural bent that way, do not excel in the pursuit of 'the wily *x*.' This is unfortunate, but the remedy lies with the men themselves. Owing to proofs of rules being given, 'Martin' will be found specially useful for such as intend going in for "Honours."

In addition to the recognised standards, a bewildering host of 'New and Short Methods' have of late years passed through the printer's hands, some of them so good in themselves as *almost* to tempt one to backslide, and forsake his old loves. But from this heresy I have been saved by being confronted with the fact that it would mar a leading feature of "Wrinkles" which I see every reason to stick to, namely, the retention of methods which, by harmonising in their general arrangements and characteristics, lead up to each other, so that the one may be a stepping stone to the next. At least such is the endeavour, so far as it is possible to carry it out. By this system the mind is not distracted by a number of problems differing widely in detail, if not in principle; nor is the memory needlessly burthened.

Not long since, an acquaintance, whilst discussing "Wrinkles," remarked—'One of its chief merits lies not so much in what *you have put into it*, as in what *you have kept out of it.*' Exactly so! He too had felt how the utility of a book might be jeopardised, if not destroyed, by offering to its readers more mental pabulum than they could conveniently digest, and more, indeed, than was actually required. 'Enough is as good as a feast,' and it *is* possible to have too much of a good thing.

Authors of the 'New and Short Methods' will please accept this in explanation of my seeming neglect.

With this edition are incorporated the 'A and B Tables,' so favourably known in the Peninsular and Oriental Co., through the instrumentality of Mr. H. S. Blackburne of that service. Interpolation—unless capable of being performed mentally—takes time, and is an unmitigated nuisance. To do away with it in most cases, and to minimise it in the remainder, I have very materially expanded both Tables. In the first half hour from the meridian the numbers are now given for *each minute;* thence to 2 hours, they are given for *every other minute;* and afterwards, interpolation being easy owing to the values changing slowly and regularly, the original 4-minute interval has been reverted to.

After mature consideration, Blackburne's auxiliary tables for finding the azimuth have been rejected in favour of the simpler and more direct process by which it can be taken out from Table C absolutely at sight, and with even more accuracy than is required by the necessities of navigation.

To include the moon, planets, and zodiacal stars, I have extended Table B to 29° of declination. The ultra-zodiacal stars have been re-computed for the epoch A.D. 1900, and sixteen others added. Since the declinations of the so-called 'fixed stars' do not change appreciably in a man's life-time, this lower portion of Table B will hold good *for position finding* till at least A.D. 1950; *for Azimuths*, practically for all time. Before 1950 comes, however, many things will have passed away, and it may be that aerial ships will have superseded marine ships, and sky-pilots have wiped out sea-pilots. *Quien sabe?*

These extensions and additions render the 'A and B Tables simply invaluable, *and immensely more complete than any similar ones extant.* It is only proper to mention that Mr. Blackburne, in the interests of the profession, and in a most liberal spirit, had unreservedly placed the result of his labours at my disposal, to be dealt with as might seem to me best. Nearly seven years elapsed before I could see my way to accept such a genuinely unselfish offer, and then only because convinced, as Mr. Blackburne also was, that if by this means the tables became better known, they could hardly fail to be appreciated at their full worth. Should their enlargement and insertion in "Wrinkles" bring about so desirable a consummation, it will be a point scored for both of us, as well as a distinct gain to the seafaring community all over the world.

Although with myself as Foster-father, both title and tables have grown stouter, and the use of the latter better developed as regards the azimuth, the tables ought ever to be more especially associated with Mr. Blackburne, as the seaman who first enlarged the scope of their far-reaching utility, to whom is due the credit of having devoted himself for years to their elaboration, and of being the first in this country to publish them in an extended form.

This is mentioned on the principle of 'Rendering unto Cæsar the things which are Cæsar's.'

So far back as 1878, whilst on the Venice line of the P. and O., Mr. Blackburne was in the habit of using that portion of the Tables—then in MS.—which was suitable to the route; but circumstances did not permit of his completing and publishing them till May 21st, 1883.

On July 1st of same year, in his *Stellar Navigation*, Rosser followed suit with an abridged set for the same purpose, which may be taken as corroboration of their value.

There is, however, a statement in Rosser's edition of Norie's Epitome that these Tables were first put into their present form in England, in 1882, in Rosser's *Stellar Navigation ;* but, in view of the above authentic facts, this is evidently a mistake. Though actually published in July, 1883, *Stellar Navigation* was not even entered at Stationers' Hall till the following December.

Table I. of previous editions, for which I was indebted to Mr. A. C. Johnson in connection with his now well-known method, has in this issue been superseded by Table C. The two are on precisely the same basis, but mine has been computed to three places of decimals, the arrangement is different, and it has been extended to just three times the size of the other. These important alterations render the Table susceptible of any degree of accuracy the worker may feel justified in going to. In Johnson's deservedly popular method the object of his Table is to find the 'Longitude correction' *from the Latitude and Azimuth,* and for this purpose he evidently considers two places of decimals sufficient. But in "Wrinkles" the introduction of the 'A and B Tables' permits of the Navigator suiting his own convenience as to whether he will follow the order laid down by Johnson as above, or, on the other hand, elect *first* to find the 'Longitude correction' from Tables 'A and B,' and *subsequently* the Azimuth from Table C. The extension of the latter permits of this being done to the nearest quarter of a degree, which is close enough in all conscience.

It will thus be seen that in the use of Johnson's method the Navigator has 'two strings to his bow.' Sometimes one will be preferable, and sometimes the other. They will not fail to speak for themselves according to circumstances.

Table D (Table II. of previous editions) has in all respects been treated similarly to C, and is therefore uniform with it. When, according to the nature of the work in hand, it suits to drop the third decimal in either of them, it can of course be done ; but there is no harm in having it 'ready for a call' if required. Like money, you may not want it at the moment, but it's handy to have it about you. Rather !!.

Should Tables be found to contain errors, they are naturally regarded with suspicion, and their value is materially lessened.

There need be no doubt as to the correctness of A B. C. and D. To make assurance doubly sure, they were entrusted to that most accurate and indefatigable computer, Captain Alfred Fry of Liverpool, to be duly and truly checked in the most rigorous fashion possible. He worked at them in Walton, and I in Neyland, some 200 and odd miles apart. Lest errors might exist in the Logarithmic Tables, which sometimes happens, he used one formula and I another. To ensure truth in the results, 7-figure logarithms were employed, and the natural numbers taken out (though not printed) to four, and sometimes five, places of decimals. Even the stereotype proofs were critically overhauled to detect possible slips in the manipulation of the type, and it was found that this precaution was necessary. Blackburne's original work was also re-computed and checked.

Altogether, so conscientiously has the entire work been done that there is every reason to believe that the Tables are free from the smallest inaccuracy, which is saying a good deal. At all events, the fact is unassailable that no similar tables published up till now can compare with them in this respect.

With regard to the amount of labour they entail, tables are very deceptive. The net result being alone visible, the user seldom has an adequate conception of what is behind. In the case before us the re-computing and expanding of A. B. C. and D. involved some reams of foolscap, many hundreds of thousands of figures, and 18 months off and on, of sight-trying work of the 'Horse in a mill' order, than which nothing can be more dismally wearisome, except perhaps the healthier occupation of breaking stones by the road-side. The 'net result' to myself so far has been a pair of steel-rimmed spectacles.

Seeing how strongly stellar observations have always been advocated in 'Wrinkles,' the omission in previous editions of a chapter devoted to star-finding, has led to my being reproached with inconsistency. The reproach is now removed and the book made complete in this respect.

In conclusion, the revision of 'Wrinkles' has had my best attention: everything in it has been considered and re-considered, turned upside down, shifted end for end, and examined microscopically. *Throughout, an endeavour has been made to awaken the interest of the student by making the subject attractive, and to train his intelligence by bringing before him whatever is novel, striking, and instructive in that particular branch of his profession to which this book is devoted.* If pains can do it, this ought to be quite a glorified edition.

I have been told more than once by the 'know-alls' of the profession that 'Wrinkles' contains nothing that is original. I meet this by referring them to my own disavowal in the preface to the first edition. In this one also there is the usual amount of Editorial scissors and paste. Many are my quotations from other books, but I have tried my best to make due acknowledgment. This is not always so easy as it would appear, for in reading a large number of works upon any one subject, as I have done in the course of my career, one's mind is sure to store up ideas without, at the time of reproducing them, being able to recollect the particular source from which they emanated. "As apothecaries we make new mixtures every day, pour out of one vessel into another; and as those old Romans robbed all the cities of the world to set out their bad-sited Rome, we skim off the cream of other men's wits, pick the choice flowers of their till'd gardens to set out our own sterile plots. . . . . As a good housewife, out of divers fleeces, weaves one piece of cloth, a bee gathers honey out of many flowers, and makes a new bundle of all."

An officer, who at various times had purchased in all some five copies of "Wrinkles," explained to the Publishers that he *never* made a voyage (well, "hardly ever") without having either to sell or give away his own. (N.B.—It is to be hoped he got 'sea price' for them).

Kind reader, should the book be so fortunate as to meet with your approval, you cannot do better than follow his *most excellent* example.

S. T. S. L.

NEYLAND, PEMBROKESHIRE,
APRIL, 1894.

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PART I.

CHAPTER I.

NAUTICAL LIBRARY AND INSTRUMENTS OF NAVIGATION.

There are so many works on Navigation—and the number thereof is ever on the upward grade—that anyone so disposed might easily convert his cabin into a book closet, thus leaving no room to stow away himself and his wardrobe. As such a proceeding would be neither convenient nor profitable, a selection from among the best has necessarily to be made. The following list is recommended as embracing all that are essential; and the intending purchaser should take care to be supplied with the latest editions. Any, or all, of them can be procured from, or through, a nautical bookseller:—

Necessary Books.

1. Raper's Practice of Navigation.
2. The Epitome the reader is accustomed to use.
3. Ex-meridian Tables; by Brent, Walter, and Williams.
4. Evans's Elementary Manual for Deviation of the Compass.
5. Owens' ABC of Compass Adjustment.
6. Allingham's Manual of Marine Meteorology.
7. De Miremont's Popular Star Maps.
8. Sumner's Method, by Captain (now Admiral) Purey-Cust, R.N.
9. Davis's Azimuth Tables, from 30° of latitude to the Equator in both Hemispheres.
10. Burdwood's Azimuth Tables, from 60° to 30° of latitude in both Hemispheres.
11. Goodwin's Azimuth Tables for the Higher Declinations (24° to 30°).
12. Johnson on finding the Latitude and Longitude in Cloudy Weather.
13. Whall's Handy Book of the Tides.
14. Bedford's Sailors' Pocket Book.
15. Admiralty Tide Tables for Current Year.
16. Findlay's Lighthouses of the World and Fog Signals.
17. Nautical Almanac for Current and Following Year.

18. The Wind and Current Charts, and the Monthly Meteorological Charts of the North Atlantic and Mediterranean, and also of the Indian Ocean, emanating from the Meteorological Office, London; the Monthly Pilot Charts of the North Atlantic, the North Pacific, etc., issued by the United States Hydrographic Office; and Sailing Directories, Admiralty or Private, for the parts intended to be navigated. Among the latter may be mentioned as worthy of special commendation:—

Findlay's North and South Atlantic.
" " " Pacific.
" Indian Ocean.
" Indian Archipelago and China.

Cost.

The above list comprises only such books as are deemed absolutely necessary in this Steel and Steam Age, when quickness, coupled with safety, bulks so largely in the calculation of profit and loss on a voyage. Their cost would be about £10—not a great expenditure when considered in connection with a Shipmaster's responsibilities; and officers co-operating with either England or America are awarded copies of the Meteorological Charts or the Pilot Charts without charge. Indeed the addition of a few more instructive works may suggest itself to some, and they will do well to obtain any, or all, of the undermentioned:—

Extra books

1. The ten Volumes of Chambers's Encyclopedia. *(Excellent.)*
2. Practical Seamanship. Todd and Whall.
3. Paasch's Illustrated Marine Encyclopedia. *(Excellent.)*
4. Popular Astronomy. Flammarion and Gore.
5. Chambers's Mathematical Tables, by Pryde.
6. Practical Physics. Glazebrook and Shaw.
7. Griffin's Nautical Series. Several volumes.
8. Any works, dealing with either Navigation or Nautical Astronomy, by H. B. Goodwin, A. C. Johnson, G. W. Littlehales, or H. S. Blackburne.
9. Know Your Own Ship. Walton.
10. Glossary of Navigation. J. B. Harbord.

The navigator who desires to pass his spare moments, not only pleasantly but also profitably, should invest in a copy of a work entitled *Azimuth*, by Lieut.-Commdr. (now Admiral) J. E. Craig, U.S.N., published by J. Wiley & Sons, New York City, U.S.A. A more attractive combination of mathematics and nautical astronomy is difficult to find.

Nautical Magazine.

To complete his working outfit, every navigator should be a regular subscriber to the *Nautical Magazine*, now published in Glasgow, and carefully read each month's number as soon as convenient after receipt. This organ of the Mercantile Marine not only affords light and agreeable reading for leisure moments, but also helps to keep the mariner closely in touch with matters—theoretical or practical—pertaining to his profession. Notices of alterations and additions in buoys and lights; the discovery of hitherto uncharted dangers; modifications in shipping laws; publication of the latest Admiralty Charts; and similar items of importance to every seaman are clearly set forth in the *Nautical Magazine* month by month.

NAUTICAL INSTRUMENTS.

To the master of any sea-going vessel other than a small coaster, the following nautical instruments are indispensable:— Compasses, chronometers, sextant, night-glasses, telescope, common or patent log, hand and deep-sea leads, parallel rulers, dividers, charts, and mercurial barometer or aneroid—both if possible. Even the coaster must carry some of the above-mentioned instruments; and, in deep-water vessels, an artificial horizon, pelorus, and a STATION POINTER should be in evidence. This last valuable instrument, until "*Wrinkles*" called attention to its virtues, had seldom or never been met with outside surveying vessels of the Royal Navy. It is, however, now used freely in both War and Mercantile Navies. To vessels frequenting narrow waters and intricate channels the Station Pointer is most especially useful; hence it should certainly be furnished to steamers trading to the Baltic, Mediterranean, Black Sea, East or West Indies, or China. The Radiograph is a cheap and fairly accurate substitute for the Station Pointer.

List of Instruments

Station Pointer.

Radiograph

It is proposed to treat of the above-mentioned instruments separately, devoting either a whole chapter or but a portion of one to each; so that, like any other good workman, the navigator may become familiar with the tools of his trade. Nothing but persevering *practice* will make him an expert in their use.

It will first, however, be convenient and in order to say something about the size and shape of our planet, the seas of which the mariner has to traverse; and to explain in what way the "knot"—his unit of speed thereon—has been arrived at, together with its precise relation to units of a like nature.

CHAPTER II.

THE MILE AND THE KNOT.

Knights of the quarter-deck, as well as laymen, are frequently just a trifle misty over this seemingly "knotty" subject. A short chapter will serve to clear away the haze and unravel the tangle.

There are three perfectly distinct kinds of miles—

Kinds of mile.

1. The Statute mile.
2. The Geographical mile.
3. The Nautical or Sea mile.

Nos. 2 and 3 are often improperly taken to be one and the same thing.

Statute mile.

The *Statute mile* is the English and American standard of itinerary measure, and was incidentally defined by an Act passed in the 35th year of the reign of "Good Queen Bess" to be '8 furlongs, of 40 perches of $16\frac{1}{2}$ feet each,' = 5,280 feet. This is a purely arbitrary measure, and has no connection with any scale in nature.

Geographical mile.

The *Geographical mile* is based upon the *size* of the earth, it being the length of a minute of arc of the earth's *equator*, and regarded as a fixed quantity in all longitudes. Assuming the equatorial circumference to be 24,902·18 statute miles, = 131,483,510 feet, and dividing by 21600 ($360° \times 60$) we get 6087·2 feet as the length of the *Geographical mile*.

But the navigator is not much concerned with either of the foregoing. When afloat he has only to deal with the *Nautical mile*, which depends for its length upon the *shape* as well as the size of the globe he sails over. In a general way we are accustomed to think of our orange-shaped planet as a true sphere, but, if we go into close detail, the flattening at the poles and other irregularities of shape will not allow themselves to be slightingly passed over as negligible quantities.

Most costly, refined, and protracted geodetic operations, undertaken by many countries during the past and present century, have settled within such exceedingly narrow bounds the size, weight, and precise figure of the globe, that it is only left to 'wranglers' to wrangle pleasantly over a trifle of a few hundred feet or so in any direction.

The polar flattening was long looked upon as the only departure from the true sphere, but the elaborate investigations of General A. R. Clarke, R.E., seem to show that the equator is not *quite* irreproachable in its rotundity, the excess of its longer over its shorter diameter being not far from half a mile. General Schubert, of the Russian Survey, independently arrived at a somewhat similar conclusion. According to Clarke, the greater axis lies in 8° 15′ west, and 171° 45′ east of Greenwich, the lesser axis being at right angles to this.* The distortion of the equatorial circumference is so small, comparatively, that its exact amount, and position of its vertices, are still under discussion and open to correction. Therefore, though a subject of interest to mathematicians of the higher order, for sailors it has no significance whatever.

Equatorial bulge.

Earth's shape.

It is quite possible—indeed, probable—that no section of the earth is either a perfect circle or a perfect ellipse, even when minor or contour irregularities are neglected. For purposes of nursery illustration, therefore, the time-honoured orange makes a capital "object lesson," more especially since it can be offered as a prize to be devoured after the lecture. Most oranges, however, rather overdo the flattening of the polar regions:—for example, in a 15-inch globe made correctly to scale, the flattening would only amount to $\frac{1}{20}$th of an inch, a quantity which could not be detected without actual callipering, so that in sea-going practice we need not distress ourselves about this little eccentricity on the part of Mother Earth. Practical Navigation is not an "exact science," and never will be.

Polar flattening.

The earth's equatorial diameter may be taken at 7926·59 statute miles, and its polar diameter at 7899·58 statute miles; the compression is therefore 27·01 miles, or $\frac{1}{293 \cdot 5}$ of the equatorial diameter. This is rather more than has hitherto been accepted, Sir George B. Airy (late Astronomer-Royal) having put the compression at 26·50 miles. If we reduce to *inches* the length of the

Earth's size.

* If confirmed, this discovery will no longer permit of the earth being termed an "oblate spheroid;" to be strictly correct, its designation henceforth would be an "ellipsoid," a geometrical figure having three rectangular axes of unequal lengths, its section in any direction being an *ellipse;* whereas an "oblate spheroid" gives a circular section if cut at right angles to the axis of revolution.

polar axis as above, we get in round numbers 500,500,500—a curious combination of figures, very easily remembered, and sufficiently near the truth for most purposes.

Equatorial circumference.

The earth's *equatorial* circumference has already been stated as 24,902·18 statute miles; this, be it observed in passing, is the longest distance which can possibly be travelled in a *direct line* (Great Circle) over its surface. It is, however, the earth's *meridional* circumference which is responsible for the length of the nautical mile. Taking the *arithmetical* mean of diameters given on previous page, this will be 24,859·7 statute miles, = 131,259,156 feet, and these, divided by 21,600, give 6076·8 feet as the measurement of the *mean* sea mile.* But why the qualification "mean" sea mile? Because, as will presently be shown, the sea mile varies with the latitude. Its length at the equator is 6046 feet, increasing to 6109 feet at the poles. The difference is not appalling, and as ships on the high seas are not navigated to yards, it is clear that the variation in the length of the nautical mile is of no importance to the sailor, further than that if he "fancies himself," and wishes to be a cut above his fellows, he ought not only to be acquainted with the fact, but also capable of giving an intelligent explanation.

Mean length of nautical mile.

Variability in length.

We have already seen that a section of the earth in the plane of the meridian—instead of being a mathematically true circle—is somewhat oval (or elliptic) in shape. If the circumference of a true circle (a compass card, for example) be divided into 360°, everybody knows that the length of each degree, or rather the space between each degree, will be the same to a hair's-breadth; not so with the oval. As its radius of curvature is variable, increasing from the extremity of the major axis to the extremity of the minor axis, and as in consequence of this the direction of the vertical will not go to the earth's centre, but meet at varying points, so on the earth's surface a degree of the meridian is found by geodetic measurement to increase from the equator to the poles. The nautical mile, therefore, varies slightly with the latitude, and it thus happens that books of reference assign to it values pretty much in accordance with the caprice of the writer and the idea pervading his mind at the moment; for example, a favourite notion is that the nautical mile should correspond to the latitude of the region most traversed by the fleets of commerce.

Oval in section.

Quot homines, tot sententiæ

Norie and others give the Admiralty nautical mile as 6,080 feet but a visit to the Hydrographer would probably lead to a repudiation on his part of that particular measure; indeed, it is doubtful if

* See Appendix E

the Admiralty lay claim to a nautical mile of any fixed length. On page 37 of the 5th edition of the *Admiralty Manual of Scientific Enquiry*—a work published by authority—the number of feet in a sea mile is given as 6075; and on another page the Table of Dip is stated to be calculated for a mile of 6060 feet.

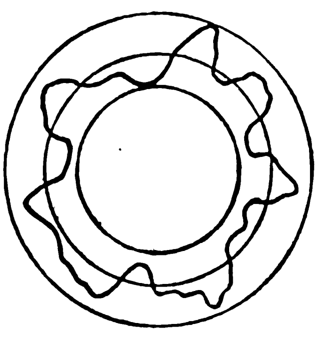
6080 feet correspond to latitude 48°, and these figures—recommending themselves more particularly on account of round numbers—are adopted throughout "Wrinkles." The *nautical mile* is therefore 800 feet longer than the *statute mile.*

Mile equivalents. For roughly converting nautical miles into statute miles, or *vice versâ*, it is useful to know that 13 nautical miles are near about the equivalent of 15 statute miles; then by simple proportion you can find the equivalent of any other number. The easiest way to do this, when an Epitome is at hand, is to open the Traverse Tables at 30°; then against the nautical miles in the Latitude column will be found the corresponding number of statute miles in the Distance column.

Landsmen, and seafarers in some instances, confound the *knot* with the *nautical mile*, and regard the word *knot* as used to discriminate against the *statute land mile.* This idea is quite erroneous! The *knot* is the world's unit of speed, the *mile* is the unit of length. One *knot*, two *knots*, etc., are speeds of one nautical *mile*, two nautical *miles*, etc., an hour. This definition should never be forgotten.

Metre. Instead of our "yard," the French and other nations use the 'metre' as their standard of length. It is assumed to be the ten-millionth part of the meridional quadrant, and was fixed by law at 39·370432 inches, in accordance with what were then accepted as the dimensions of the earth. But taking the dimensions here given, the length of the metre should be 39·377786 inches. This last may be termed the 'ideal' metre, in contradistinction to the other or 'legal' metre. **Legal and ideal.**

Universal Datum plane. By way of finish it will be interesting to glance at one or two points in connection with those extensive national surveys already alluded to. But little reflection is needed to shew that where exactness is sought after, all measurements of the earth's surface —whether vertical or horizontal—must be referred to a common datum plane. Looking at the figure, the question at once pre-



sents itself:—At what distance from its centre are we to measure the circumference of the globe, or, in other words, at what part is its diameter to be taken? Is the circumference to be taken as the outer circle representing the summit of the highest mountain (Everest, 29,000 feet); or is the middle circle, representing the *mean sea level*, to be taken; or lastly, is it to be the inner circle, representing the profoundest depths of the ocean?* It is evident a great deal depends upon the answer.

Ocean depths.

There can be no doubt that the *Mean Sea Level* is the natural and only reference plane that can be employed for the purpose. In measuring the "base line" of a survey, it is necessary that the altitude of every part of it above the level of the sea be determined, in order that the measured length may be reduced to what it would have been had the measurement been made on the surface of the sea itself. At first sight it would seem as if there were no special difficulty in determining the *mean sea level*, but, as a matter of fact, *all* measurements of the earth's surface are very much hampered by its uncertainty. Observations seem to prove that the sea level does not coincide everywhere with the geometrical figure which most closely represents the earth's surface, but may be raised or lowered here and there under the influence of local and abnormal attractions. Matter attracts matter, as ships in a calm are said to draw near to each other. So it happens that the absolute height of lofty mountains above *mean sea level* is difficult to arrive at on account of the permanent distortion of the neighbouring sea surface by the attractive force of their own masses.

Mean sea level.

Gravitational attraction.

Distortion of sea surface.

Thus it has been calculated that the Himalayas ought to heap up the waters of the Bay of Bengal to the extent of 500 feet: but in reality they fail to do so, and it follows that what would be the undeniable action of the Himalayas, if of average density, must be counteracted by some occult influence. Science fortunately comes to the rescue. The observations made at the various stations of the Indian Meridian Arc have brought to light a physical fact of the very highest importance and interest, namely, that the density of the strata of the earth's crust under and in the vicinity of the Himalayan Mountains, is less than that under the plains to the south, the deficiency increasing as the stations of observation approach the Himalayas, and being a maximum when they are situated on the range itself. General

Earth's crust, density of.

* The greatest depth so far recorded (September, 1906) is 5,269 fathoms, in 12° 43′ N. 145° 49′ E., by U.S.S. *Nero*, Captain H. M. Hodges, U.S.N. In 30° 27′ S. 176° 39′ W. red clay bottom was found at 5,155 fathoms; the U.S.S. *Dolphin* got bottom at 4,662 fathoms in 19° 35′ N. 67° 43′ W.; and 3,428 fathoms has been obtained in 19° 1′ N. 81° 2′ W. Bottom was also reached at 4,030 fathoms in 0° 11′ S. 18° 15′ W. In 11° 22′ S. 116° 50′ E. a depth of 3,293 fathoms is on record; 110 miles from the Kurile Islands there is 4,655 fathoms; between Tonga and the Friendly Isles, 4,500 fathoms; near the Ladrones, 4,478 fathoms; near Pylstaart, 4,428 fathoms; and 50 miles off the coast of Peru, 4,175 fathoms.

Clarke shews that the form of the sea level along the Indian arc departs but slightly from that of the mean figure of the earth. As explained above, subterranean tenuity is the cause, and thus the non-appearance of the attraction which this gigantic range ought to produce is satisfactorily accounted for.

Unequal density.

The Chilian Andes, from their greater nearness to the Pacific, have been computed to exert an influence on the sea level equal to 2,000 feet, but it is probable that in their case, also, this is, for the most part, nullified by want of solidity in the earth's crust; for what more likely than that, in the process of upheaval, subterranean voids have been left corresponding more or less to the elevations. Ben Nevis, which contains about a couple of cubic miles of matter, is said to produce in the neighbouring sea an elevation of three inches.

Ben Nevis

Dr. A. Supan, in "Petermann's Mitteilungen," called attention to the fact that, according to the most recent measurements, particulars of which have lately been published, the old hypothesis, that there were *important differences* in the levels of the seas of Europe, is no longer tenable. The statistics given in the "Bulletin Annuel de la Commission de Météorologie du Département des Bouches du Rhone" (1891), show that the mean level of the water at 38 stations in the Adriatic, Mediterranean, Atlantic, English Channel, North Sea, and Baltic, differs in most cases but a few centimetres from that at Marseilles, so that, for practical purposes, it may be taken that the mean sea-level on all the coasts of Europe is much about the same. It will be some years yet before this can be definitely settled. Meanwhile the conclusion cannot be avoided, that measurements of heights above the sea level as commonly stated, though fairly comparable one with another *over a limited area*, are subject to no little uncertainty if regarded as absolute quantities referred to the ideal sea level of the *mean* terrestrial ellipsoid.

European mean sea level

Now, for the same reason that *mean sea level* is not quite uniform for all parts of the world, the plumb-line, usually considered a model of rectitude, does not hang truly vertical everywhere. This is the same as saying that the surface of the mercury in an artificial horizon is not truly level everywhere. Just consider the effect of this on the more delicate astronomical observations of a survey, and the knowledge and skill required to eliminate such errors.

Verticality of plumb-line.

In mountainous countries, as near the Alps and in the Caucasus, deflections of the plumb-line have been noted to the extent of 29".

Ocean depths.

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Verticality of plumb-line.

In mountainous countries, as near the Alps and in the Caucasus, deflections of the plumb-line have been noted to the extent of 29″.

Curious deflections.

Russia.

Scotland.

On the other hand, deflections have been observed in *flat* countries; for example, at certain stations in the vicinity of Moscow, within a distance of 16 miles the plumb-line varies 16″ in such a manner as to indicate a vast deficiency of matter in the underlying strata; but, luckily for the surveyor, these are exceptional cases. Here is another nearer home. On the north coast of Banffshire, near the village of Portsoy, there is a spot at which the deflection amounts to 10″, so that if that village were laid down on a map in a position to correspond with its *Astronomical* latitude, it would be 1,000 feet out of its proper place, since a second of arc (″) about equals 100 feet on the earth's surface.

Zenith.

Astronomical or *Observed Latitude* is the angular distance from the equator of the *apparent* zenith; or it may be expressed as the *Declination of the apparent zenith.* It is consequently dependent upon the direction of the plumb-line, since it is this latter which gives us the vertical point known as the zenith.

Various directions of the plumb-line.

Now, it has been shown that the plumb-line is subject to disturbance; but when not disturbed, it coincides with the normal of the true ellipsoid, and, therefore, indicates the *true* zenith.

Direction of earth's centre.

The normal to the undisturbed surface of mercury in an artificial horizon, that is, the undisturbed vertical at any point of the earth's surface, is not in the direction of its centre except at the Poles and the Equator.

The *Geodetic* or *Geographical*, or *True* Latitude, is the angle which this normal makes with the plane of the equator. On the other hand, some mathematicians consider the *true* zenith to be in the external prolongation of a line from the earth's centre through the place of observation. But, properly speaking, this is the *Reduced* zenith.

Sometimes termed the "*Reduced*" Latitude.

Geocentric Latitude, not mentioned hitherto, is the angle at the centre of the earth subtended by the arc of the meridian between the place in question and the equator. It is therefore independent of the earth's shape.

"Angle of the vertical."

The *Geocentric* is always less than the *Geodetic* Latitude, except at the equator and poles, where the two coincide. The maximum difference (11′ 44″) is in Latitude 45°. As the Navigator has only to deal with *Astronomical* Latitude, he need not worry over these fine distinctions.

With the foregoing intricacies before the mind, one can have some slight inkling of the exceedingly delicate and high-class mathematical character of the observations and calculations required in an extensive geodetic survey, such, for instance, as our own "Ordnance Survey," or the huge undertaking known as the "Great Trigonometrical Survey of India."

Verily, brother, there are more things in Heaven and on earth than are dreamt of in the simple philosophy of seamen!!

CHAPTER III.

THE MARINER'S COMPASS, AND IMPORTANT FACTS CONNECTED WITH IT.

Curiously enough, until comparatively recently, ship-builders and owners did not bestow on the compass the amount of consideration which it undoubtedly merits. It is *pre-eminently* the instrument upon which the safety of the vessel depends, and justly ranks *first* in importance. It would be easier to dispense with the Chronometer, or even the Sextant, than with this invaluable guide. With a faulty compass, a straight course cannot be made. Formerly, when time was less an object than it is now, a bad landfall, or distance lost on the voyage through zigzagging over the ocean, was of no particular moment; but in these days of keen competition, when the public look for the arrival of Trans-Atlantic and other mail steamers almost to the very hour, and the rival companies wage paper wars over the splitting of minutes in the passages of their respective vessels, it is necessary that *good navigating appliances* should back up *good ships.*

Apathy of builders.

Rivalry in making passages.

Compasses for use on board ship are of two classes—the Standard and the Steering Compass. Taking them in this order, the Standard first claims the reader's attention.

Standard Compass.

To begin then, it is of the *greatest importance* that a spot should be selected for the Standard compass where it would only be acted upon *by the general magnetic character of the ship, and not by particular masses of iron in its immediate vicinity.* To this some builders pay considerable attention, whilst others, unfortunately, seem unaware of the necessity for such a precaution, taking it for granted that the compass adjuster can effect his object, quite irrespective of how the compass may be fenced in with iron.

Placing of Standard Compass.

Position important.

The Standard may not inaptly be termed the "Navigating compass." By it the course should be set, and all bearings taken for ascertaining the ship's position. To this end, it must be placed where an *all-round* view of the horizon can be had, excepting, of course, when the masts or funnel intervene. In vessels of the larger class a special platform is erected, and in such cases the handrails and supports are of wood or brass. Unless, however, the whole structure is firmly and securely bolted down to the hull of the ship, it will be certain to vibrate in strong winds, or with much motion, and so destroy the steadiness of the card, rendering almost useless what may otherwise be a good compass.

Box Binnacle. The binnacle should be large enough and of such a shape as would permit of the adjusting magnets being placed *inside,* instead of on the deck. This is a neat and compact arrangement, and access to the interior can be had through a small door provided with *a good patent lock and key.* To prevent tampering with the magnets, or the inside being made use of by quartermasters as a handy stow-hole for odds and ends, this door should be religiously kept locked, and the key in the possession of the captain.

Gray, of Liverpool, was about the first to bring out a binnacle embodying this principle; or, to be more correct, it was a square stand or box, upon which the binnacle proper was placed. To the late Lord Kelvin is due the credit of having brought into fashion a really satisfactory form of binnacle; and, with modifications, the bulk of compass-makers have followed suit.

The Kelvin Binnacle. One of the great advantages of the plan is that when it becomes necessary to remove the binnacle for any purpose—such as caulking decks, &c., there is no occasion to disturb the magnets; whereas when they are nailed to the deck round about the binnacle, it will sometimes happen that they are taken up by caulkers ignorant of the mischief they are doing; and when replaced—as likely as not the magnets are shifted end for end, and put down at a greater or less distance from the compass than they occupied previously.

Danger from proximity of iron. When the Standard compass is improperly situated—as, for example, on a narrow bridge, hemmed in by iron hand-rails, flanked by boats' davits, awning-stanchions, ridge chains, stokehold ventilators of large size with *moveable cowls,* and probably not two feet from the iron stand of the engine-room telegraph, or twice that distance from the donkey boiler,—it is rather too much to expect that its behaviour will be satisfactory. No adjuster in the world could even *pretend* to compensate the errors of such a compass. He might certainly manage, by a liberal use of magnets, to lick it into something like shape for the time being; but such an adjustment could not be depended upon for twelve hours after it was effected, especially in a new vessel, and on a voyage to the southward the deviations would soon become so large as to be unmanageable.

Large errors before compensation.

Compasses are not infrequently so badly placed that the adjuster has to compensate errors amounting to eleven or twelve points.

The reader may imagine that the foregoing is an overdrawn picture, but if he will take the trouble to look around, he will not be long in finding how true its description is. Sometimes, too, it occurs in steamers that the end of a trysail-boom, when guyed amidships, comes within 18 inches or less of the compass. In this case, if the foot of the sail should be made to haul out with a traveller, on a massive iron jackstay—a very common mode of fitting now-a-days—it is clear the effect on the needle will entirely depend on the position of the boom, whether eased off to port or starboard, topped-up, or in the crutch.

Height of compass above deck.

The writer was in one vessel where the *wire* toppinglifts of the main-boom came down within six feet or so of the Standard compass, and were proved to produce an effect of 5° when the boom was guyed over from one side to the other. Precaution, then, should be taken, that no iron *subject to temporary removal,* be within ten or twelve feet of the compass; and the latter should stand at least 4 feet 6 inches above the deck, not only on account of the beams, but to avoid the liability of being influenced by any moveable article of iron *on the deck next below it.*

One compass affecting another.

It is common enough, where the vessel is steered forward, to find a compass placed on the bridge just above the one in the wheelhouse.* In such cases it is imperative that the upper or bridge binnacle should be raised above the deck as much as possible, or the compensating magnets contained within it will affect the other compass in the wheelhouse, and *vice versâ.* If raising the binnacle on a wooden stool or solid block should render it inconveniently high, it is not a killing matter to build a suitable step—or even a couple of them—round about its base. The reciprocal action of one compass and its magnets upon another—more particularly in the position here referred to—is a thing very likely to be overlooked from the mere fact of the compasses not both being seen at one and the same time.

* See diagram facing page 39.

Fitting out new ship.

When fitting out a new ship, it is not uncommon for the builder to consult the wishes of the future captain in the matter of compasses, &c.; if, however, the latter does not join the vessel till she is nearly finished and ready for delivery, it will be too late to expect much in the way of alteration, as builders, at all times averse to it, are particularly so when they are just about to make the vessel over to her owners. But there is no reason why the captain, if dissatisfied with the existing arrangements, should not *himself* endeavour to remedy them in the course of some subsequent voyage. It is an easy matter with a spare compass to make trial of various places about the decks, until one is hit upon comparatively free from the influence of the ship's iron, and *there* the Standard should be rigged up, even if other important matters have to give way for it.

Alterations in position.

Neutral spot of ship.

It is well to know that in every vessel there is a "neutral spot" where a compass would have little or no deviation; but unfortunately, it may be found to exist in an impracticable position. Nevertheless it is worth looking for. There is only one caution necessary—before finally screwing down the binnacle in the newly found neutral spot, be sure that it is *really* so by testing the deviation on two adjacent cardinal points, such as north and east, as it may happen that a place has been hit upon where the compass will be tolerably correct on one point and very much out on another. It is questionable, however, whether this neutral spot would deserve the name in all latitudes.

Fixity of tenure.

The writer is led to the above remarks by having noticed that the Standard compass of ships several years old had been allowed to remain from the commencement in most unsuitable positions, as if their captains considered, that once placed, there they should for ever remain.

The following is a description of a Standard or Navigating compass—honest and simple—which has stood the test of several years' trial, and been found to fulfil all the desirable conditions in a fair degree:—

Lecky's Radial Line Card.

In point of size it is a compromise between the justly lauded Admiralty Standard compass and the gigantic ones which, until recently, were in use on board some of the Atlantic Mail Steamers. In the attempt to gain steadiness, and secure large marginal divisions to steer by, the cards of these last-mentioned compasses sometimes attained the amazing diameter of 18 in. and 20 in. The card under description has a diameter of 11 in., and is mounted similarly to the Admiralty one, on two pairs of needles, respectively $8\frac{1}{4}$ and 6 inches in length, by half an inch in depth, and $\frac{1}{40}$ of an inch in thickness. The longer pair occupy the central position, the ends of each being 15° from the north and south line, whilst the outer, or short needles, are each 45° from the same point, after the manner represented in Diagram No. 1. The needles, as will be seen, are secured to the card on

Position of needles.

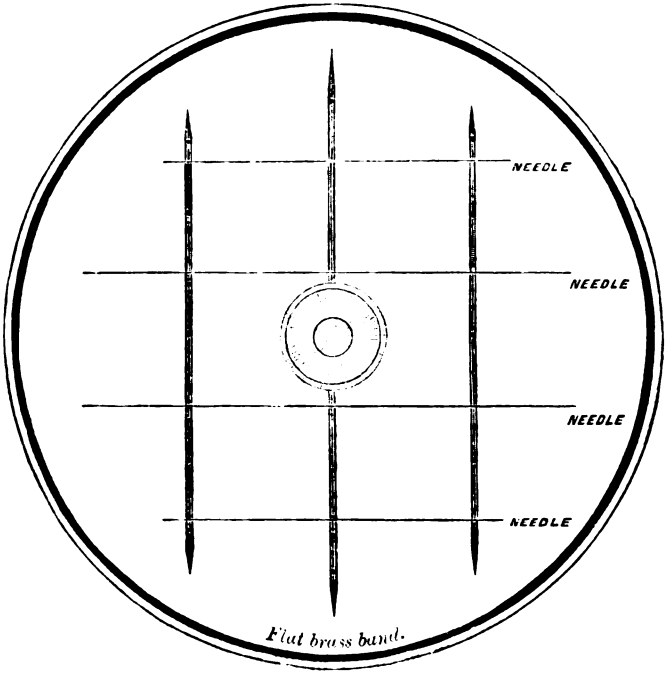


Diagram 1.

their edges in the usual way, are parallel to each other, and equidistant. By this arrangement *the advantages of a large card* are secured without *the drawback of long needles*, which are objectionable for many reasons: the principal being that they are opposed to a perfect compensation of the compass by magnets, and that there is no practical gain of directive power, the latter being more than counterbalanced by the friction on the point of support, resulting from the increased weight. It follows from this last, that in all compasses the needles should be very thin, and the brass or aluminium carriers as light as possible.*

Short needles and large card

* There will be no loss of power consequent on thinness, as magnetism resides principally in the surface.

It may be laid down as a fundamental principle that *the smaller the needles, the more correctly they point; and the larger a card the more accurately it is read.* When very large needles are used, *sluggishness* results, which the unwary navigator is too apt to mistake for *steadiness.*

Sluggishness.

Who has not seen a piece of marline or spun-yarn made fast to the compass bowl, and occasionally twitched by the man at the wheel to "keep the card alive," or, as it is termed in Jack's phraseology, "to keep the compass afloat." Independent of long needles, there are many causes to which this state of affairs can be traced, and they will be referred to further on.

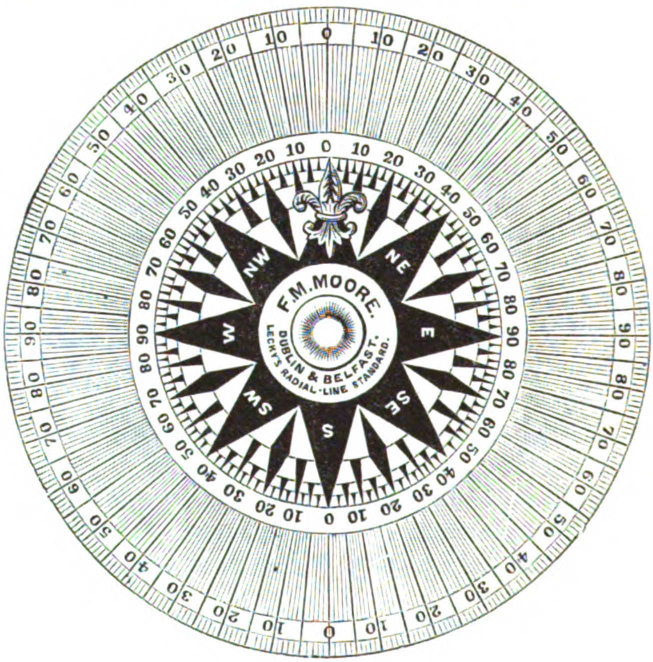


Diagram 2.

In steamships the course should be set in degrees.

It will be noticed, by reference to above diagram, that the upper surface of the card is of novel pattern. The outer rim is divided by radial lines into single degrees, every fifth and tenth being, for sake of clearness, marked stronger than the others. Now that the course—on board steamships at least—is very commonly set in degrees, this, which might otherwise be considered an objection, is no longer one. Each quadrant is numbered by tens, from zero at north and south, up to 90° at east and west.

The diameter of the central space, representing the usual points and half points, is 6·35 inches, and the length of the Stile or Shadow-pin mounted on the centre of the card is so proportioned (3·75 inches), that when the sun attains a greater elevation than 50°, its shadow will fall *within* the before-mentioned radial lines —showing at once, without reference to anything else, that the altitude is no longer favourable for observing azimuths. In this respect the compass is self-indicating.

Lecky's card self-indicating.

It is true that bearings of the heavenly bodies may be taken with other instruments up to altitudes of even 60° or upwards; but to get a *correct* azimuth, when the body observed is so near the zenith, necessitates a much more refined instrument than the ordinary ship's compass.

As a rule, *except under great pressure*, azimuths should not be taken at a higher altitude than 30°; in fact, the nearer to the horizon, the better.

To continue the description of this form of Standard compass,— the glass cover of the bowl is of a curved form, struck with a radius of 6·5 inches, to allow room underneath for the play of the Shadow-pin; and the bowl, of stout copper, is suspended by six strong india rubber supporters to an additional or inner brass ring. This last arrangement, now in tolerably common use, diminishes the shocks which would otherwise be communicated to the card by the jar of the engines and propeller, and by the pitching of the vessel in a heavy head-sea. These may be lessened still further by placing a light spiral spring in the socket of the pivot which sustains the card.

Essentials of a good compass.

In a *well made* compass of the ordinary pattern, the *essentials* are—that the pivot should be accurately centred in the bowl; that is to say, that its point should be exactly in the intersection of the two diameters, passing through the centre of the gimbals, and in the same horizontal plane; the upper edges of the needles should also lie in the same horizontal plane, or, *if anything*, an eighth of an inch lower. To avoid distortion from shrinking, the card should be mounted on its mica base *before printing*, otherwise the graduation of the marginal divisions is likely to be in error. The shadow-pin, if there is one, should not only be straight, but accurately centred on the card, and the general balance of the instrument so well preserved that the shadow-pin will stand truly vertical under all circumstances.

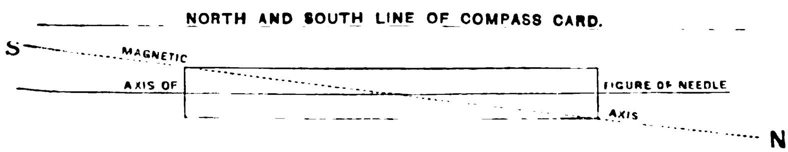
The compass should be *sensitive* in *smooth*, and *steady* in *rough* water.

Hang of the bowl.

The bowl, if inclined to list one way or the other, can be made to hang horizontally by neatly serving the gimbal-ring with lead wire; and in case the card itself should be a little out, some melted sealing wax sparingly dropped on the under side will speedily restore its balance. The card, when poised on its support, should not be more than $\frac{3}{4}$ of an inch below the upper edge of the bowl where the latter meets the glass cover, otherwise the sun would require to have considerable elevation before its shadow could strike down on it. Moreover, the higher the level of the card, the easier it is to take bearings directly by the eye. The pivot should have a fine point of hard steel or iridium, ground to fit the sapphire cap, and the magnetic axes of the needles must be strictly parallel to the north and south points of the card.

Reasons for mounting needles on edge.

Before going further, it may be as well briefly to explain one of the reasons why in modern compasses the needles are secured to the card on their edges, instead of on their flats, as formerly. As just stated, it is necessary, for obvious reasons, that the *magnetic* axes of the needles should be parallel to the meridian line of the card. Now, when needles or steel bars are magnetized, it sometimes happens that the poles do not lie exactly in the *axis of the figure*, but obliquely to it, *vide* diagram; in which case, if



mounted on their flats, the above condition could not be conveniently fulfilled, but by mounting the needles on their edges it can.

If the foregoing points are conscientiously attended to in the manufacture of the instrument, it will be found to give good results, and prove steady in a seaway. This latter quality may be still further ensured by attaching a flat circular band of brass to the *margin* of the card, on its under side, something after the fashion of the fly-wheel; its effect is to increase the vibrational period of the needles by throwing the weight to the outer edge, and in this manner it is a most valuable auxiliary in conferring steadiness on the card. The dimensions of the brass ring are, $\frac{2}{10}$ of an inch in width on the flat, and $\frac{1}{10}$ of an inch in thickness. Lord Kelvin has ingeniously availed himself of this principle in his patent Standard compass, which has proved such a wonderful success.

With Lecky's radial-line compass, azimuths of the sun or moon can readily be taken by simply watching where the shadow falls on the radial lines of the card. If partially veiled by clouds, so as to cast no shadow, a little practice will enable anyone to take a direct eye-bearing of the sun (if not too high) with a probable error of less than a degree. Bearings of objects on the horizon, such as ships, land, or lights, can be obtained with the utmost accuracy, by getting the Shadow-pin, margin of the card, and object in the same straight line. The writer and his officers have over and over again observed azimuths of stars—taking 3 or 4 on widely different bearings as a check. When worked out, the results generally corresponded within a degree, and never exceeded two degrees, even when the vessel had considerable motion.

Taking azimuths and bearings.

See that the compass has not lateral end-play in the gimbals, which would jar the card, and cause it to oscillate every time the ship rolled. If the gimbals do not fit close up to the sides, insert a small piece of soft wood, but do not jam them or impede their action.

See also that the freedom of the card is not interfered with by its edges touching the bowl; this sometimes happens with a too-neat-fitting card when expanded by damp. Test it by spinning the card on its supporting pivot.

Stile or Shadow-pin.

In taking azimuths by the shadow of the sun or moon, the extreme convenience of the Stile is at once demonstrated. In smooth water the reading on the card can easily be made to half a degree, or under; at less favourable times, the swing can be observed and the mean taken. There is no stooping or manipulating of a refractory azimuth-ring and speculum, the use of which, when the bearing happens to be on the beam, is rendered additionally awkward in compasses fitted with chain-boxes; nor does one's nose get smeared with oil and brickdust that may be left on the brasswork by a careless quartermaster or lamp-trimmer.

Swinging ship.

In swinging ship for a deviation table, there is nothing to do but stand still, with book and pencil in hand, and, as the ship is steadied on the required point, note the reading of the shadow simultaneously with the hour and minute by watch, previously set to Apparent Time at Ship. In fact the observer is master of the situation without an effort. With this compass, swinging the ship completely round, steadying her on every other point, should not occupy more than 30 or 35 minutes.

Some compasses are still fitted with a Shadow-pin, to ship in a socket on the glass cover; but there are several serious objections to this arrangement. The pin, from its exposed position, is continually getting bent; if removable, it gets lost; if left on, and the binnacle top be hurriedly shipped or unshipped, it is apt to get a knock, which will probably break the glass, and cause no end of inconvenience.

Best arrangement of Shadow-pin.

Again, it is seldom that the Shadow-pin is stepped exactly in the same vertical line as the centre of the card, which ought *strictly* to be the case if a correct result is looked for; the sun has to attain quite a considerable altitude before the shadow can possibly fall on the card; and finally, from the motion of the bowl and the card not being always coincident, the shadow on the latter ranges about much more than it need do.

On the other hand, when the Shadow-pin is mounted on the card itself, it does not suffer by handling; if made straight, it will remain so; it is protected from injury; it is more easily centred; and from its curved shape the glass cover is stronger.

Principle of azimuth instruments.

The correctness of *all* the various instruments used for taking azimuths depends, in the first place, upon certain of their parts preserving either a true horizontal or vertical position, so that, if the objection be made to a Shadow-pin on the card, that it may not always stand truly vertical, it must not be forgotten that it applies with equal, if not greater, force to all the other modes of observing: and it is this liability of instruments to deviate from their proper position, whether vertical or horizontal, that makes it advisable to take azimuths at low altitudes, whereby any errors due to this cause are reduced to a minimum.

Balance of card.

To test the balance of the card is a simple matter. First of all unship it and assure yourself that the shadow-pin stands exactly at right angles to its surface; this can be done with an ordinary set-square. Next, replace the card and put on the glass cover; then, standing at a convenient distance from the binnacle, and the helmet or top being removed, stoop sufficiently to make the shadow-pin appear to grow out of the sea horizon beyond. A good eye will now have no difficulty in judging whether or not the pin is at right angles to the true horizontal line.

But this is only half of the test, since, though the pin may be all right when looked at from one point of view, it may be very much out from another: therefore examine it a second time in a direction eight points to the right or left of the former one, and if the pin still continues upright, its verticality on all other points is definitely established. Thus if the ship should be steering west, and you make the first trial along the N.W. point of the compass, the second trial should be made either along the N.E. or S.W. point.

If, however, the pin should be found inclined to one side or the other, note carefully the direction of its inclination, and having unshipped the card, drop a little melted sealing-wax on the under and opposite side, close out to the edge. Replace the card, examine it afresh, and repeat the dose until the result is satisfactory. It is best to do this on a smooth day, when the ship is upright and steady.

Sealing-wax as a counter-poise.

If the card should get overloaded with sealing-wax, it is easy to chip it off when hard.

The compass just described was contrived by the writer, and is a comparatively cheap and thoroughly useful form of Standard. It is unpatented, and can therefore be made by any optician, and, to avoid the expense of a fresh plate, mounted impressions of the card can be had through the post for a few pence from F. M. Moore, 102, High Street, Belfast, who has constructed compasses on this pattern.

When the owner's pocket can afford it, however, there is no Standard compass which in any way can rival the one invented and patented by Lord Kelvin. Its mechanical construction is as near perfection as may be; and looking at it either theoretically or practically, it has advantages which no other known compass possesses.*

Lord Kelvin's Patent Compass.

Unfortunately there is considerable misapprehension abroad as to this compass; the writer has heard men, who ought to have known better, say, "Oh! it is too complicated for ordinary folks." Now there could not be a greater mistake than this. The entire arrangement is beautiful in its extreme simplicity, and there is absolutely nothing to get out of order.

Simplicity of the 'Kelvin' Compass.

"The proof of the pudding is in the eating of it," and five years' experience of Lord Kelvin's compass in all weathers and climates has convinced the writer that it is no more liable to a mishap than any other kind—perhaps not so much, whilst the facilities for adjusting it stand unrivalled. We next come to

* This was written in 1881, but since the expiry of the patent, compass-makers generally have adopted the principle of short needles. In other respects, also, their compasses and binnacles approach the type of Lord Kelvin's; so that, in some cases at least, there is not much difference between them.

THE STEERING COMPASS.

Spirit Compass.

Among the best is one in which the *card* is *almost* floated in diluted spirits of wine.* The bowl is, of course, hermetically sealed, to prevent the escape of the spirit; and in the better descriptions there is a compensatory arrangement, which permits, without injury to the several parts, the expansion and contraction consequent on change of temperature.

Advantages of Spirit Compass.

The objects of this form of compass are, first, to diminish the friction due to the weight of the card on the pivot, thereby materially increasing its sensitiveness, and secondly, to render the compass steady in heavy weather, or when placed in positions where there is much tremor arising from machinery or otherwise.

Flotation power.

The flotation power of the card is so adjusted that, though the latter is several ounces in weight, its pressure on the point of support does not exceed 15 or 20 grains. The bowl should be so completely filled by the spirit as to leave no air-bubble. If one should at any time appear, the bowl must be unshipped and turned upside down, to permit of the deficiency being made good through the proper filling hole, which is then closed by a screw-cap and washer. *On no account must the glass cover ever be started.*

Protection from strong sun.

There is only one other caution necessary in the use of liquid compasses. In tropical climates they should be carefully shielded from the rays of the sun, which, if permitted to beat upon them, would turn the card a dirty yellow, and eventually, a brown colour; besides risking the breakage of the glass top, owing to excessive expansion of the spirit. From neglect of this simple precaution the writer has seen several liquid compasses come to grief most unexpectedly, causing much annoyance during the rest of the passage, and expense at the end of it.

Boat Compass.

This is the only kind of compass which is suitable for boat work; in all other descriptions the card swings so much as to be useless.†

An erroneous idea sometimes prevails, that, in an iron vessel such a compass is less affected than those of the common pattern. This is really not the case, nor do the makers wish to convey

* Pure alcohol—familiarly known as spirits of wine—is preferable to water, or any other liquid, because it does not freeze even at very low temperatures.

† In the best liquid compasses the card is of hard enamel, which permits of *pure* spirits of wine being used without discoloration, and renders freezing impossible. These points can never be gained in the ordinary painted card.

such an idea. As explained above, a card, when *nearly* afloat, is much more sensitive and obedient to the earth's directive force than the same one would be if suffered to rest its whole weight on the sustaining pivot, and that is all. The writer cannot here do better than quote the late Mr. Towson's remarks on this subject. He says, on page 122, in his work entitled "Practical Information on the Deviation of the Compass for the use of Masters and Mates":—

Impossible to intercept magnetism.

"In connexion with compass deviations, many practical men have vainly attempted to discover some substance or medium that would insulate the needle from the influence of the magnetism of the ship's iron. Many imagined discoveries of this character have been patented, and have served both to waste the time and money of the patentees, and to distract the attention of the mariner from that class of study which alone can promote his safety in navigating an iron ship. It may be stated with confidence that there is no available medium that can intercept magnetic influence. For two centuries, at least, every class of bodies has been submitted to experiment, in order to discover a material capable of intercepting the influence of one magnet on another, not for the purpose of preventing deviation, but because the mechanic clearly perceives that if such a material were discovered, a motive power could be produced by various arrangements of permanent magnets and insulating bodies. But no one has succeeded in making this discovery. Should, however, the efforts, which for centuries have been unsuccessful, be realized, although a new motive power would thereby be available, it would be altogether valueless in connexion with the compasses of iron ships. The magnetism of the earth generally, the loadstone, soft iron, hard steel, or the electro-magnet, is all of the same nature. If we shut off one, we shut off all.

"If, therefore, we could succeed in insulating the needle from the magnetism of the ship, we should by the same means intercept the magnetism of the earth, and thus the compass would be rendered absolutely useless. In the first place, then, the object sought for is not available; and, secondly, if such a medium did exist, it would be entirely valueless in connexion with the compasses of iron ships."

Popular errors as to causes of deviation.

There is an ill-defined idea prevalent among the older school of pilots and seamen that the compass is affected (1) by fog; (2) by strong winds of long duration in the same quarter; (3) by the phenomenon known as the *Aurora Borealis* in the northern, and *Aurora Australis* in the southern hemisphere; (4) by the attraction of land—notably when of volcanic origin, and by the proximity of the vessel's keel to the bottom in the shallow waters of harbours, rivers, and estuaries; (5) by thunderstorms.

These are the causes principally blamed for abnormal deflections of the needle; whether justly or unjustly remains to be seen.

Fog.

The two first may be disposed of very shortly. It can be stated in the most positive manner that neither *mechanically* nor *magnetically* does fog affect the compass in the slightest degree. There is no difference in the magnetic constitution of a needle which has the good luck to reside on shore as compared with one whose misfortune it is to be buffeted about at sea. This being admitted, we would have heard long ago if the doings of the needles in the basement of the Observatory at Greenwich had been at all erratic during fogs, of which London can boast some very fine specimens. There is also a magnetic department at the National Physical Laboratory, near Richmond. In both these, the delicately-suspended needles are so arranged that their slightest movement is automatically registered on sensitized paper—in fact, photographed. Nothing out of the common can therefore occur without being detected, also the precise time of its occurrence. It is therefore easy to trace connection between the behaviour of the needles and any outside phenomena supposed to influence them, as the latter are also registered, though in a different manner.

Hard-hearted winds.

The same thing, of course, applies in the case of winds of long duration, such as the stiff-necked easterly "blows" that, in the spring of the year, used to drive scores of "homeward bounders" into Queenstown and Falmouth, and to a lesser extent do so still. Should the vessel be of iron, the deviation due to what is described further on as "Retained" magnetism might be the culprit, inasmuch as, after a long stretch on one tack, with head pretty much in same direction, an iron vessel would have her ordinary magnetic character temporarily altered, so that when a shift of wind permitted a change in the course—say from north to east—the deviation on the new course would be found different to what it had been on east previous to the setting in of the spell of contrary wind. This is probably the origin of the belief, and though *indirectly* it might as shewn be accountable, wind, *as such,* could not deflect the needle a single hair's-breadth.

We will pass on to No. 3, which is much more interesting.

Influence of the Auroræ.

Aided by the photographic camera and spectroscope, substantial progress in solar physics has been made within the past twenty years or so. Sun-spot observations have been systematized, and it is now accepted that the *mean* period of their recurrence is eleven years, though individual periods may depart from it considerably. For a long time it has been made evident that there is a decided connection between this period and that of terrestrial magnetic phenomena. That is to say, they are more frequent and more pronounced at times of maximum sun-spots. The records shew that magnetic storms, as they are termed, mostly occur when an exceptionally large spot is visible near the central meridian of the sun's disc, or about the time of some great change in a sun-spot. It has been established, also, that these magnetic disturbances take place at the same absolute time over the entire earth.

Sun-spots.

The spot-group on the sun February 5-17, 1892, was the largest photographed at Greenwich since 1873, in which year was commenced the Greenwich series of photos. Its presence was associated with a correspondingly large magnetic disturbance, which attained its maximum on February 13-14. It began on the 13th, about 5·32 P.M., was at its best between midnight and 2 A.M., and gradually died out about 4 o'clock the same evening, thus lasting nearly 24 hours. It seriously disturbed the telegraph and telephone services *throughout the world*, and was attended by one of the most brilliant auroral displays seen of late years in this country. At Greenwich, the needle for recording the variation was pulled out of the meridian line 1° and more. At Kew, the same occurred; whilst at Potsdam, "enormous" fluctuations were noticed: *changes* of 2° in two minutes were recorded, and deflections of 1½° were observed. (Dear reader, please note that *changes* or *vibrations* of 2° were considered "enormous."). November of 1882 was marked by a disturbance falling but little short of the one just described.

Magnetic storm.

In investigating the relationship between large sun-spots and magnetic storms, it appears that one or more will usually occur during the life of any particularly noticeable sun-spot; and a curious point—so far unexplained—is that these disturbances are more common in spring and autumn than at other times: thus, taking the Greenwich records for the last 50 years, disturbances are two or three times more frequent before and after the equinoxes than at the solstices.

Season of disturbance

A preliminary sudden movement is a common feature of magnetic storms. It may be taken as a warning of the disturbance to follow in a lesser or greater number of hours, but sometimes the disturbance follows on at once.

Auroras and sun-spots are found to wax and wane together even in their smaller fluctuations, but the theory that they depended for their frequency on the influence and position of the planets had to be abandoned. Beyond question, the Aurora is an electrical phenomenon, *something* after the style of sheet lightning. According to Lemström, who, by overspreading the top of Mount Oratunturi, in Northern Russia, with a network of insulated wires, succeeded in producing identical effects, the Aurora is due to currents of positive electricity illuminating the atmosphere in their passage to the earth. The vertex of the luminous arch is always found in the direction of the magnetic meridian, and as the display is known to occur simultaneously in both hemispheres, it shows, as might be expected, a connection between the magnetic poles of the earth.

Cause of Auroræ.

It is abundantly proved that the very largest magnetic storms do not pull the most delicately balanced needles more than 1½° out of the magnetic meridian. How then about the rougher instrument of the mariner? Further, the effect of these disturbances is more in the direction of causing small *vibrations* of the needle than in holding it over for a length of time to the right or left of the line of rest: in fact, a man might pass his life at sea, and not experience a steady pull of 1°.*

Amount of disturbance on board ship.

Enough has been said to shew that auroral displays, magnetic storms, and periods of solar activity, are each coincident with the other, and productive of magnetic disturbance; but even in their most intense form the amount of such disturbance would seldom be appreciable on board ship, certainly never so great as to approach even a quarter of a point.

Should, then, unusual deviation be *proved* to exist during a time of fog, a long continuance of wind from one quarter, or during a display of the Aurora, the navigator may put these three "suspects" on one side, and look in some other direction for the cause.

Anyone can test these matters for himself. In thick fogs it is often beautifully clear overhead and the water smooth, so that 'Time Azimuths' can readily be taken of Sun, Moon, or Stars, which can be repeated *after* the fog has cleared off: and these observations can be further compared with those taken *on the same course* a short time *previous* to the fog setting in. The same can be done with the Aurora, and all doubts set at rest. In like manner, when passing close to islands known to be magnetic —such as St. Helena, Pantellaria, or the Salvages—a series of

Azimuths during fog.

* See Appendix F.

careful azimuths would do more to convince the sceptic than any amount of "ink-slinging." Besides, why should any one particular ship be selected for a manifestation of this kind, when thousands of others, under similar circumstances, had been allowed to go scot-free. It is altogether unreasonable, unless the magnetic demon is guilty of favouritism.

Author's own experience.

The writer would wish it understood that the foregoing is strictly borne out in his own experience at sea. Whenever opportunity offered, most careful experiments were made to confirm or disprove all such theories, and though many thousands of azimuths have been taken by him in such parts of the world as he has visited, and at various hours of the night and day, in no single instance was anything abnormal detected which could not otherwise be satisfactorily explained.

No. 4. *The attraction of land, and the effect produced by proximity of vessel's keel to the bottom.*

Attraction of the shore.

This comes under the heading of "Local Attraction"—a term which will be more fully explained in another place: suffice it to say here, that it has reference only to the effects on the compass of magnetic forces *external* to the ship in which such compass is placed. From time to time one hears extremely foolish accounts of wreck through the supposed attraction of land. The writer recollects one in particular, which, from his familiarity with the locality, made rather an impression. It was that of a fine large steamer stranded near Cape Santa Maria in the River Plate. "Fools step in where angels fear to tread," so some sage newspaper correspondent attributed her loss to the effect of an imaginary magnetic hill somewhere round about that neighbourhood. This gentleman had probably been reading the story of *Sinbad the Sailor*, and how, on getting near one of these magnetic hills, its attraction was so powerful as to pull all the nails out of the ship's side, and down she went, plump O!! As a matter of fact, the steamer was lost through ignorance of the north-easterly current which invariably runs on that coast with great strength during a Pampero.

Sinbad the Sailor revived.

Pretty much the same thing appeared in the Press when H.M.S. *Serpent* came to grief near Cape Finisterre in Nov. 1890, but it was clearly shewn in evidence at the court-martial, that even had there been any "Local attraction" thereabouts, its effect would have been to keep the vessel *off* shore.

Magnetic laws do not permit of the supposition that visible land will disturb the compass of a ship at sea, because the effect

Distance law of magnetism.

of a magnetic force diminishes in such exceedingly rapid proportion as the distance from it increases, that it would require a local centre of magnetic force of an amount absolutely unknown to affect a compass half a mile distant. It has never been disputed that masses of rock are sometimes intensely magnetic, and quite overpower the earth's magnetism *when a compass is placed sufficiently near.* There is nothing new in this. For example, in the account of the voyage of H.M.S. *Beagle* during the survey of Tierra del Fuego, about the year 1830, it is mentioned that several times when the 'Kater's' Standard compass was *taken on shore* to get bearings, the "Local Attraction" was so excessive that the card had no directive force whatever, and observations were impossible. On returning to the *Beagle* the effect disappeared, though the vessel was *close in* with the same land.

Compass vagaries.

The writer recollects full well that, during the time the western part of the Strait of Magellan had to be navigated with fearfully imperfect charts, it was a regular thing to hear recounted, with a face as long as the main to'bowline, how in such and such channels the compasses had "jumped" two points or so, and had nearly put them on shore. It was no use attempting to convince the narrator to the contrary. These "jumps" are never heard of now: the magnetic phantom who delighted in these pranks has been exorcised by the modern surveys of Wharton and others, which shew that the previous charts were frequently whole *points* in error. In the intricate channels leading from the Strait to the Gulf of Penas, the writer, during the six years he used them, found errors of 3 and 4 points to be quite common; but azimuths there-and-then *always* exonerated the compass, though the land was sometimes not more distant than half the length of the vessel. The distance traversed in these channels was about 350 miles, with neither lights, buoys, nor beacons: sometimes a dozen or more of islets would be passed where *none* were shewn on the chart; and sometimes a number appeared on the chart which were invisible elsewhere. It was a splendid place to teach one to keep his eyes open and his wits about him.

Pleasant channels to navigate.

The law which has hitherto been found to hold good as regards "Local attraction" of magnetic rocks is, that north of the magnetic equator the *north-seeking* end of the compass needle is attracted towards any centre of disturbance; south of the magnetic equator it is repelled. Now, in the case of the *Serpent,* steering south, the effect, had there been any (which was certainly *not* the case), would have been to cause easterly deviation, and, as any one may see, easterly deviation would have taken her off shore, as already stated.

So far so good, but in some unaccountable manner it has hitherto been overlooked that while a ship is such a distance from visible land as to be altogether beyond reach of possible magnetic influence, she may, *in shallow water*, be passing closely over ferruginous rocks capable of producing very decided magnetic effects on her compass. This, however, was not the *Serpent's* case, as the water only shoals near Cape Villano when close in to the coast. **H.M.S.** *Serpent.*

Some instructive cases of this kind have come to light within the past few years: one instance is furnished by observations of the Variation of the compass on the east coast of Madagascar. The normal lines of Variation for several miles southward from St. Mary's Isle should vary from about 11° W. to 12° W., but instead of this, the French men-of-war, which are frequently running up and down this part of the coast, find that the Variation near the shore at St. Mary's Isle is only 6° or 7° W., the north end of the compass being repelled by the nature of the bottom. These results tally with observations made on shore in Madagascar, New Zealand, and other places. **Bed of sea magnetic.**

There is a similar area of magnetic disturbance in the Adriatic, which was examined at the request of the late Father Secchi, the astronomer; but by far the biggest thing in this way was discovered near Cossack by H.M.'s surveying schooner *Meda*—a wooden vessel employed on the marine survey of the north-west coast of Australia, a part of the world which is known to be highly magnetic in places. In July of 1885, the *Meda*, in passing at night, found a sudden deflection of two points in the neighbourhood of Bezout Island, but was unable to investigate the cause until the following September, and then only partially. But in 1890, H.M.S. *Penguin*, then carrying on the survey, was employed to look into the matter more fully. It was supposed by the *Meda's* officers and others that the island of Bezout was accountable for the vagaries of the compass in that neighbourhood, but Captain Creak, R.N., F.R.S., the then Admiralty Superintendent of Compasses, adjudged it to be a magnetic ridge *under the sea*, and this proved to be the correct view. *Meda's* **discovery.**

On November 4th, 1890, the *Penguin* being at work in the neighbourhood, the magnetic elements were obtained on shore near Reader Head, but nothing remarkable was found either in Dip, Declination, or Force. On the 5th, the ship was swung

H.M.S. *Penguin's* experience.

twice when 3 to 6 miles from the shore. On the first occasion there was a very slight indication of unusual variation. Leaving Port Walcott on the usual track in the afternoon, when Bezout Island bore S. 79° W. (true), distant two miles, the north point of the compass was suddenly deflected two points to the westward, just as had happened to the *Meda*, though not quite on the same ground. The ship was immediately anchored, and some hours of the next day were spent in examining this anchorage and locality generally; the soundings gave 9 fathoms throughout. Observations were also made during this time *on* Bezout Island (the nearest *visible* land) of the absolute values of the three magnetic elements, but, notwithstanding the short distance separating the island from the ship, *the results were normal.*

On board the *Penguin*, the instruments employed were the standard compass, situated 68 feet above the bottom of the sea, and a Fox dip-circle, about 6 feet higher. It was found that the centre of the disturbance was about 50 feet in diameter. Drifting slowly over it from N.W. to S.E. three or four times, the greatest disturbance of the Standard compass was produced by a force repelling the north end of the needle: this amounted to 23° of deviation when on the N.W. side of the centre, and to 55° on the S.E. side.

Amount of dip.

The ship was anchored for four hours, *nearly* over the centre of disturbance, the north-seeking end of the compass needle remaining constantly repelled as much as 50° to 55°. When *exactly* over the centre, the observed dip was 83° S., the normal value for the general locality being 50° S. The north-seeking end of the dip-needle was therefore repelled *upwards* to the extent of 33°, though at the same time—from being vertically over the focus—the Standard compass shewed but little deviation.

These large values of 55° in the Declination (Variation), and 33° in the Inclination (Dip), were confined to a very small area, the values of the disturbance in both elements *decreasing rapidly* as the centre was passed in any direction. The position of the *Penguin's* centre of disturbance was Bezout Island (beacon on summit), S. 79½° W. (true), distant 2·14 miles, and was 1·3 miles from the *Meda's* centre of disturbance.

Re-examination by *Penguin*.

A further, and, in some respects, even more detailed examination was subsequently made of this interesting locality with the following results:—Within the limits of an area four miles long north-east and south-west, by two miles broad, with a depth of

8 to 9 fathoms at low-water springs, and bottom of quartz-sand, and shells, the compass was disturbed from 1° at the outer limits to as much as 56° near the focus of the disturbing force. Over this focus the dip-needle shewed 81° 10′ S., the north-seeking end being thus repelled upwards 31°. The greatest *range* in deflection of the Standard compass was 86°, viz., 56° to the east and 30° to the west, confirming the previous occasion's observations. This place happens to be on the line of No Variation.

Such deflections of the compass are due to magnetic minerals in the bed of the sea under the ship, and *when the water is shallow and the force strong*, the compass may be temporarily deranged when passing over such a spot, but the area of disturbance will be small, unless there are many centres near together. *Observations prove that disturbance of the compass in a ship afloat is experienced only in a few places on the globe.** The excess of red magnetism found near Cossack, as above detailed, is a most unusual occurrence, and need not give navigators the nightmare. It, however, teaches a lesson. Observe azimuths as often as possible. Half his time, the officer of the watch is walking to and fro the bridge doing absolutely nothing. Why should this be, when he might be usefully occupied—not with a scraper or a paint-brush, 'tramp' fashion—but in contributing his quota towards the safe navigation of the ship? **Rarity of such localities.**

The minor question of compass disturbance by proximity of the vessel's keel to the bottom in frequented harbours, rivers, and estuaries, need scarcely be touched upon; not that it is impossible, as shewn above, but because there is no authentic instance of such a thing having happened. When iron vessels first came out, it was even conjectured that the anchor and chain cable, acting as media between the hull and ground, produced an effect upon the ship's magnetism sufficient to cause deviation of the compass. There was an air of plausibility about this, but experiments have demolished it, so far at least as well known anchorages are concerned. It does not appear that it occurred to the *Penguin's* officers to test this hypothesis in the locality of all others most likely to produce an effect.

Thunder-storms. 5. Here we have, beyond doubt, the most fertile source yet alluded to of possible compass disturbance, and disturbance of a more or less permanent character. *Ordinarily*, thunderstorms do not derange the compass, as has been proved over and over again; but there are many well authenticated instances where, when iron vessels have been actually *struck* by lightning, their

* See Appendix G.

magnetic character has been so completely altered as even to cause reversal of the pointing of the needle.

Iron hulls never damaged.

Now, though the hull of an iron vessel may be, and has been, *struck* by lightning, there is no record of its ever having sustained *damage*—indeed, such a mishap would seem to be impossible. Iron is a good conductor, and water is still better; therefore, when struck by lightning, the hull gives the electric fluid a free passage to the surrounding sea, where it is at once harmlessly dissipated. Wood, on the contrary, is a non-conductor, and, by resisting the current, is made to suffer accordingly.

MORAL.—It is unwise to oppose anything or anybody stronger than yourself.

Hence it is not uncommon to hear—even in iron vessels—of the wooden spires of masts, and, more rarely, other fittings of the same material, being rent and shattered like matchwood. Masts composed entirely of iron from truck to keel would "determine" the discharge at their highest points, and secure perfect immunity from *damage.*

It is conceivable that an iron vessel might be within the radius of a severe thunder-storm without being what is called "struck" by lightning, owing to the vast conducting surface of the hull steadily, but, in most cases, invisibly, draining off the diffused electricity in the circumambient air before it had time to concentrate and develop into either of the energetic forms known as Forked-lightning and Ball-lightning—the hull acting, in fact, as a sort of electric safety-valve. This is probably the condition when corposants (St. Elmo's fire) are seen sitting on the mastheads and yard-arms, and luminous Will-o'-the-wisp-like appearances silently chase each other down the wire rigging and funnel shrouds.

Violent forms of lightning.

As the matter has a really important bearing on safe navigation, it will be dealt with at some length. Perhaps the most satisfactory and convincing mode of treating it will be to narrate a few bonâ-fide experiences. The one referring to the *Sedgemore* was related to the writer, and subsequently communicated to him on paper by her captain.

When off Nantucket, on a passage from Liverpool to New York, the White Star steamer *Germanic,* Captain Kennedy, encountered an electric storm of unusual strength and duration. It came on at midnight, July 11th, 1884, and ended at 8 o'clock the following morning. A very peculiar accompaniment was a fog, so dense at one time that the funnels could not be seen from

Lightning during thick fog?

the bridge. The lightning was from every quarter, forming a complete network of flashes. The illumination of the fog was so thorough and sustained that the ship appeared to be in a continuous blaze or halo of light. The soundings not agreeing with the reckoning, led Captain Kennedy to conclude that his compasses were affected, and so it proved.

At noon on the 12th, the true position was ascertained, and on shaping the course from Fire Island to Sandy Hook, the ship had to be kept W. by S. ½ S. by compass, instead of W. ½ N. as usual, thus shewing an error of two points due to the electric storm. The account goes on to say that the Standard compass was so much affected during the storm, that for some two or three hours it was perfectly useless, and dependence had to be placed on the wheel-house compass (Lord Kelvin's), though it also was affected. On the homeward passage it was found that the errors on easterly courses were the same as usual. **s.s. *Germanic.***

Now the possible conclusion to be drawn from this last statement is, that in the interval the *Germanic* had recovered her normal magnetic character.

It is a pity that the foregoing account is not more circumstantial in details; its scientific value is absolutely *nil*. The next case is much more circumstantial, and consequently of considerable value: it is also more recent.

On March 28th, 1892, when crossing the Gulf Stream (lat. 38½° N., long. 67½° W.), homewards from Baltimore to Liverpool, the (s.s.) *Sedgemore* encountered a strong north-east gale, with heavy rain, thunder, and lightning. Corposants were constantly hovering about the mastheads. At 0hr. 45m. A.M., during a squall, there was a loud report, sharp and defined like the firing of a cannon, with a concussion that shook the ship throughout: at the same moment she was enveloped in a fierce light that penetrated to every part. **The *Sedgemore* electric storm.**

The masthead electric light—carried on the foreside of the *wooden* fore topgallant mast — was destroyed, and the mast slightly charred all over. The copper wire conductors were also destroyed from the lamp downwards *until they reached the iron mast, after which they were uninjured.*

The steering compasses in the fore and after wheel-houses were completely reversed: the ship's course at the time by the forward one was E. by S. After the ship had been struck, this compass shewed W. by N., and moved in the opposite direction to the ship's head; for example, when the helm was ported and **Reversal of ship's magnetism** the ship's head came to the right, the compass appeared to say that she had gone off to the left. Later on, when observations had been obtained, Captain Trenery tried to adjust this compass. First, the fore-and-aft magnets were reversed, but without the slightest effect. Then these magnets were replaced in their former positions, and the 'thwartship magnet was reversed, when the card immediately spun round to east, working freely, but with the original deviation on this point increased considerably. Previous to the attempt to correct this compass, spare ones had been tried in the same binnacle, but the results in every case were exactly the same.

The 'Kelvin' Standard on the upper bridge was not reversed as the others were, but was rendered sluggish, and had largely increased deviations. The following Table shews the change for the points on which azimuths had been taken.

Alteration in Standard.

Ship's Head.	Dev. before.	Dev. after.	Ship's Head.	Dev. before.	Dev. after.
North	0°	22° E.	E. by N.	2° W.	10° W.
N. by E.	0°	20° E.	East	4° W.	15° W.
N.N.E.	0°	15° E.	E. by S.	6° W.	20° W.
N.E. by N.	0°	10° E.	E.S.E.	8° W.	23° W.
N.E.	0°	5° E.	S.E. by E.	10° W.	26° W.
N.E. by E.	0°	0°	S.E.	12° W.	29° W.
E.N.E.	1° W.	5° W.	S.E. by S.	14° W.	31° W.
			S.S.E.	15° W.	33° W.

Looking at the column of "Dev. before," the writer can scarcely bring himself to believe that the errors recorded as between North and E.N.E. were determined *at the same time* as those between East and S.S.E. The latter look very like the result of "Retained" magnetism, and if so, ought to have shewn a corresponding but contrary error on North, &c., if belonging to the same series of observations.

When the compasses were re-adjusted in Liverpool, it was found necessary to reverse all the magnets of the Standard, and to add several others. In the case of the Steering compass, the 'thwartship magnet was kept reversed as Capt. Trenery had placed it, but had to be moved much closer to its work; the other magnets remained in their original positions.

Reversal of *Sedgemore's* magnetic character.

Both compasses and adjusting magnets were found to be in good order, which proved (so said Capt. Trenery—and the writer agrees with him) that the effects produced were solely due to change in the polarity of the ship's magnetism.

On May 18th, 1892, when in lat. 28° 12′ N., long. 70° 50′ E., the s.s. *Capella*, commanded by Captain Woodcock, had a somewhat similar experience to that of the *Sedgemore*. The morning had been squally, with rain, thunder, and lightning. About 7·30 the storm seemed to have passed over, and the weather shewed signs of clearing up, when, after a considerable interval, there was a very vivid flash, accompanied by a violent explosion close to the rail near the starboard fore rigging, which seemed as if something had exploded and scattered sparks and fire over the ship. The *wooden* foretopmast was splintered near the spire, and some service torn off the backstay, probably by a branch from the main current. The compass on the upper bridge was deflected from N. 72° W. to N. 45° W., and remained that way for a short time. The wheelhouse compass, which had previously shewn W.N.W., indicated E.S.E., and the one on the poop was considerably affected also. Trial in the wheelhouse of a spare compass-card shewed that it and the original card were all right, but the shock had reversed the magnetism of the ship. Later on, the deviation of the upper bridge compass on N. 72° W. was found to have increased from 9° W. to 19° W. **Electric explosion.**

At 4 P.M. same day, the *Capella* was swung completely round, and errors ascertained.* They had very much altered. The deviation on north had changed from 6° W. to 27° W. After making the circle, the wheelhouse compass regained some of its directive force, as the north point again pointed somewhere towards the north.

As the compasses did not go back to their original errors, they had to be entirely re-adjusted.

Such is the *Capella's* experience, which quite corroborates that of the *Sedgemore*. Leaving out the *Germanic* for reasons already given, two things are made plain: (1) that the compasses themselves had maintained their directive force intact; (2) that the normal magnetic character of both vessels—for an unknown period of time—had been completely overwhelmed by the new magnetism imparted by the shock. Each ship had virtually been made an electro-magnet by the terrible intensity of the discharge. **Deductions from *Sedgemore* and *Capella*.**

It will be noticed that the wires communicating with the electric mast-head lamp of the *Sedgemore* were completely destroyed as far down as the point where the iron mast commenced. This simply means that the copper wires were not large enough in themselves to carry off the electricity until supplemented by

* The date of *previous* swinging is not given—an unfortunate omission in an investigation of this kind.

the iron mast, when they received immediate relief, and escaped further injury. Copper is between five and six times a better conductor than iron, but in this case the wire was much too small for so heavy a discharge. One of ¾-inch diameter, projecting two or three feet above each truck, and carried down to perfect contact with the iron mast, would probably have saved all *damage;* and if carried down overboard to water, and *properly insulated from the ship,* would probably have saved the compass *disturbance* as well. The bridge compasses were, as might be expected, less troubled than those nearer to the hull. This is the case in all vessels where the bridge compass is kept clear of *local* iron, such as mast, funnel, stanchions, &c.

It would be interesting to know if the *Sedgemore* and *Capella* ever entirely recovered their previous magnetic state. There is no doubt that after a lapse of time they would part with *some* of the super-posed magnetism, but how much it is impossible to conjecture.

The foregoing amply demonstrates the absolute safety of iron vessels at such times. Wooden vessels, unprotected by lightning conductors, would almost certainly have been set on fire—a not by any means uncommon occurrence in olden times.

This is a fit place to refer to experiments made in 1866, by Mr. Evan Hopkins, C.E., of London, who went so far as to patent a process whereby he hoped to depolarise iron vessels, and leave them thenceforth free from any compass-disturbing influence whatever. For this purpose he employed a number of Grove's batteries and electro-magnets. The latter were to be passed along the plates till the desired end had been obtained. The inventor was careful to explain that the process must not be overdone, for fear of *re*-polarising in the opposite direction. Evidently the idea was incapable of being carried to a successful issue, as it very quickly died a natural death.

Position of Steering Compass.

In a large vessel where, to gain power, the wheel is of considerable diameter—say 7 feet or upwards—*two* steering compasses are absolutely necessary, each so placed, to starboard and port, that the helmsman may have the compass directly in front of him, no matter at which side of the wheel he may be standing. If there should happen to be but *one* compass, an error, due to parallax, will be introduced in the course. Looking at the compass in an oblique direction causes an apparent change in the relative positions of the lubber-line and the marginal divisions of the card—the greater the clearance between the edge of the card and the compass bowl, the greater the error. Unless the helmsman can get the centre of the card and the lubber-point in one with his course, he is sure to steer to one side of it. Where, from the inconvenient closeness of a skylight, stanchion, or other deck fixture, a single midship compass is unavoidably placed very near to the wheel, or is so placed because the steersman's sight will not define the degrees at a greater distance, this error or parallactic displacement of the lubber-line is aggravated, amounting frequently to a quarter of a point. Now, in a moderate day's run of say 300 miles, in thick weather, this becomes a serious consideration, as it affects the ship's position at the end of it to the tune of 15 miles. Hence the necessity for a compass directly facing the steersman, which should be as far distant from him as may be compatible with distinct vision; and to this end its diameter ought not, in the case of a spirit compass, to be less than eleven inches. If constructed, however, on the principle patented by Lord Kelvin, there would be a great advantage in increasing the size to fifteen or even sixteen inches.*

Parallax a source of error.

By placing the compass as far forward of the wheel as possible, it is less within the influence of the iron spindle, tiller, rudder-head, and stern-post, all of which in an iron vessel are powerfully magnetic. If, however, as is frequently the case now, the after-wheelhouse should be constructed wholly of iron, with possibly an iron deck in addition, and steam steering gear, it seems certain that *trustworthy* compensation by magnets must be extremely difficult, and only to be accomplished after a lengthened investigation of the nature of the many forces acting on the compass. The same may be said of compasses in the conning towers and turrets of ironclads.

Iron fittings.

In sailing vessels it is not uncommon to find an attempt made to remedy this liability to error, when steering with a single compass in the midship line, by having the binnacle containing it made to slide over from side to side as required; but it is easy to see that, even in a wooden ship, such an arrangement is far from advisable, as the iron spindle of the wheel must affect the compass in a different direction every time the latter is moved across. However, there is nothing like *trial*, and when the ship is in the graving dock, or at sea in a calm, with perfectly smooth water, the sliding binnacle can be tried in both positions; but the result

Sliding Binnacles.

* Lord Kelvin has constructed 15-inch steering compasses which have been found by the writer and others to give excellent results.

cannot be considered satisfactory *unless the experiment is tried with the ship's head in different directions.*

Steam Steering Gear.

Now-a-days large steamers are steered by steam, one man, with a miniature wheel about 30 inches in diameter, sufficing to control the movements of the vessel's head. In this case one compass is all that is necessary, as the helmsman stands *directly behind* the wheel, the spindle and pedestal containing the connections being immediately on the fore side.*

It is necessary here to say a few words touching the fittings, as, unless particularly specified, they are not always made of *brass*. In one large mail steamer commanded by the writer, the spindle of the wheel and vertical shafting communicating with the steam-steering engine were actually made of *iron*, though their ends came within *seven inches* of the compass. How the maker had the hardihood to venture on such a petty economy, involving such serious consequences, it is difficult to say. The iron work alluded to was enclosed in a brass pedestal, which would have concealed it most effectually; but fortunately, before the ship was delivered to her owners, the matter was discovered and reported to the builders, who insisted upon the maker substituting a brass spindle and 8 feet of brass shafting for the iron. One cannot therefore be too wide-awake in these things when looking after the finish of a new ship.

Concealed Iron.

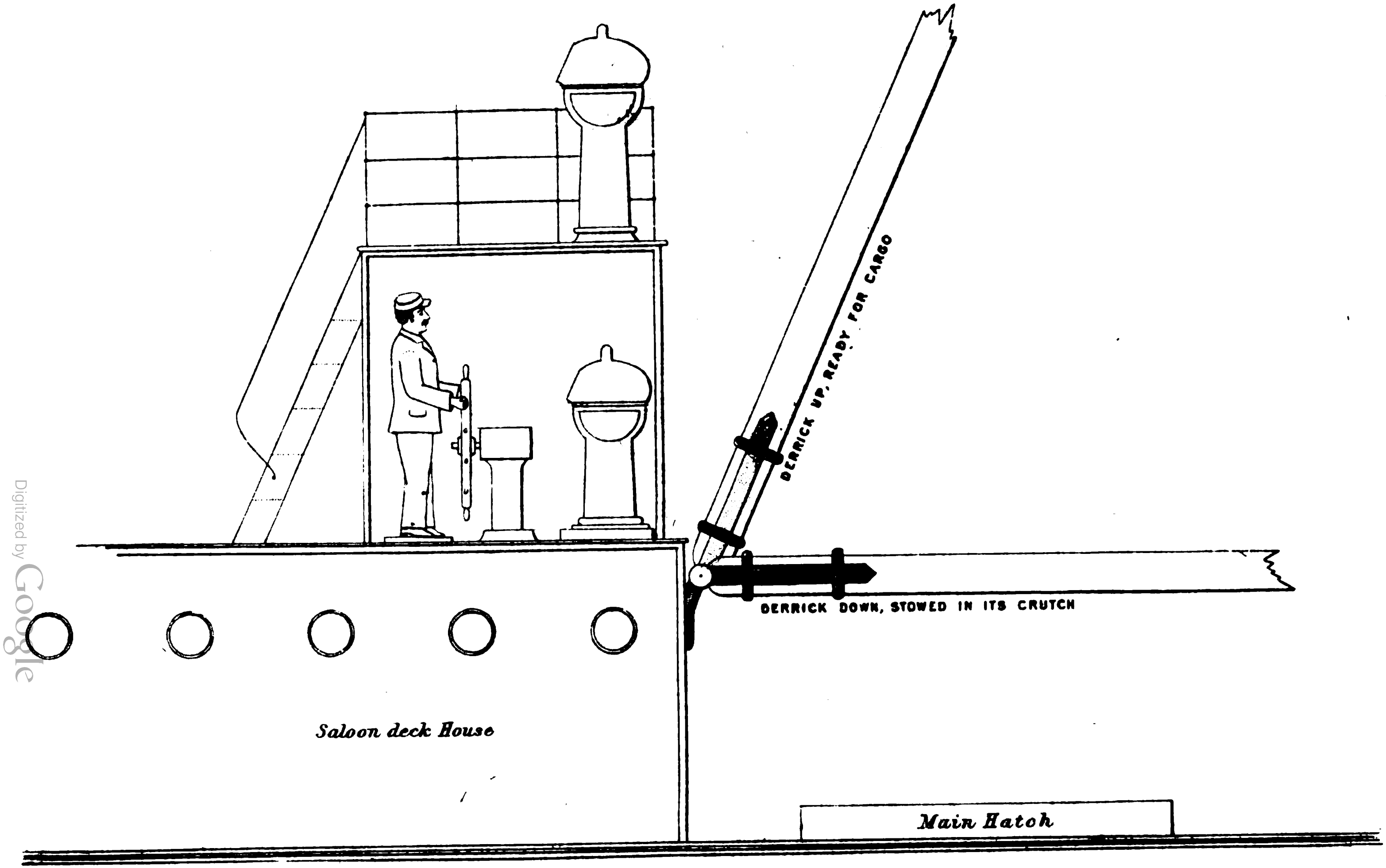
In the same vessel there was a large teak skylight, almost touching the wheelhouse on the fore side; and to prevent the leaves of the skylight warping with the heat of the sun, one of the foremen caused three iron brackets, or stiffeners, to be screwed firmly on the under side of each leaf, and was very much astonished when told that every time the skylight might be opened or shut, that the compass in the wheelhouse would be affected to the extent of several degrees. Nothing short of actual trial would convince him that such would be the case—his argument being, that as the wooden bulkhead of the wheelhouse intervened, the iron brackets could not possibly disturb the compass. However, the question was set at rest soon after, when the compasses came down from the maker. The disturbance caused by opening and shutting the skylight amounted nearly to half a point, so the after iron brackets were removed, and brass ones substituted.

Iron stiffeners.

In another large steamer, also commanded by the writer, the heels of the main hatch cargo derricks were fitted into sub-

Iron in ambush.

* *Vide Diagrams* 12 *and* 13, page 600.



TO FACE PAGE 38

stantial iron shoes, shaped something after the fashion of a tuning fork, and connected by a pin to the lugs of the goose-neck in the usual manner.

Each shoe was four feet long, and firmly secured to its derrick by a couple of stout iron bands driven tightly on over-all. This mode of fitting is good and strong, and every way superior to the common rag-bolt. Reference to the diagram facing this page will show that the derricks were stepped on the forward break of the saloon deck-house in such a manner, that when raised to plumb the hatchway the upper ends of the shoes came within three feet six inches of the wheelhouse compass, and on about the same level as the card.

Now, as the iron shoes were neatly let in flush with the surface of the wood, and as moreover the derricks—from head to heel—were plenteously smothered in mast-color paint, after the manner of steamboats in general, it was not likely that any one would readily suspect the presence of so dangerous and well-ambushed an enemy.

Lurking danger exposed.

On the 24th of October, 188—, when going round from Portsmouth to Liverpool, it was decided to try what effect would be produced on the wheelhouse compass by placing the derricks in their usual working position. The ship at the time was some ten miles to the westward of the Bill of Portland, and the course steered was West (corr. mag.). Azimuths were taken with the derricks in the two positions shewn in the diagram, and the difference in the compass between "derricks up" and "derricks down" *amounted to no less than* 18°!!! The Bridge compass being well elevated, proved to be beyond the influence of the iron shoes, as it was not affected in the slightest degree. Can it be wondered, then, that vessels are lost without those in charge being able to account for it. Regular comparisons, *at short intervals*, between the Standard and Steering compass should be a standing rule on board ship, and would materially assist in the detection of "foggy" cases like the above.*

When a rag-bolt is buried in the heart of the spar, it is even less likely to attract attention than the shoe is.

Magnetic insulation impossible.

Some men fancy that by covering an iron stanchion with canvas, and then painting it, or by sheathing it with brass or Muntz's metal, they can destroy, or rather shut off, its magnetic influence on a compass; but unfortunately this is *totally im-*

* The reader need not worry over the blue and red shading just at present. It will be fully explained in the chapter on Compass Adjustment.

possible. As already stated in these pages, no substance has ever been discovered which will accomplish this.

Magnetism penetrates all bodies.

It cannot be too strongly impressed on the sailor's mind that if a given piece of iron produces, say ten degrees of effect, on a compass at a distance of three feet, it will produce precisely the same effect if the space between them should be built up *solid* with any non-magnetic material he chooses to name. Cranks wasted time and ingenuity seeking a substance to shut off the magnetic action of an iron ship on her compasses; regardless of the fact that the earth's directive action must then cease, and the compasses become useless.

Proper position for Steam Steering Engine.

There appears to be a diversity of opinion among shipbuilders as to the proper place for locating the steam-steering engine. Some have it amidship, on the main deck, just under the fore-wheelhouse; whilst others prefer to place it in the after-wheelhouse, where it is controlled from forward by means of very simple shafting, leading aft under the deck. Allusion is here made to this only in so far as it has to do with the compass. Where the engine is placed aft, it is possible at all events, to have the steering compass in the *fore*-wheelhouse tolerably free from iron in its vicinity, and on this account, if on no other, it should be so placed. Fortunately this plan possesses mechanical as well as other advantages which renders its ultimate adoption a matter of certainty.

Masthead and Pole Compasses.

Before quitting the subject of compasses, there are a few more points to be noted in connection with it. In a ship fitted with a Mast, Tripod, or Pole compass, it would be an excellent plan to consider *it* as the "Standard compass," and the one on deck otherwise known by that name to be called the "Navigating compass." Mast compasses, when properly constructed by experienced makers, and well placed, are often very reliable. Their deviation is very small in amount, *and much more constant* than compasses nearer the hull. Nevertheless they are apt to defeat their object and abuse the confidence reposed in them, if stupidly placed near wire rigging, iron caps or bands, iron-stropped blocks, chain tyes, or haulyards, &c.

If, therefore, in a steamer, it should be decided to have a Mast compass (and in the writer's opinion no iron steam vessel should be without one), proper provision must be made for it—the mast, of course, must be of wood, the rigging of rope, and the above precautions followed out to the letter. It is scarcely likely however in these days, when there is the alternative of a Pole compass, that owners will incur so much trouble and expense.

The ship's course should always be *set* by the "Navigating compass," *checked* by the "Standard compass," and *referred* to the "Steering compass" by a signal agreed upon, such as the whistle in general use among officers.

Comparisons needful.

All observations should be made by the *Navigating* compass.

It is clearly impracticable to ascertain the deviation of the Standard (mast) compass by *direct* observations, although it can be done very easily by a method described further on, under the heading of Friend's Pelorus, or still more easily by comparison with another compass, the error of which has already been determined. The same applies to the steering compass when inside a wheelhouse.

Elevated Compasses wear more rapidly.

Mast or pole compasses require more looking after than others. For example, the increased motion aloft causes extra wear and tear of the pivot point and jewelled cap. These should be examined at frequent intervals, *especially if the ship should be in a rough weather trade.* The magnifying glass found in all sextant cases, and a fine sewing needle, serve to scrutinize the cap. If the stone is found to be flawed, it should be at once replaced with a spare one, of which several are generally supplied in a first outfit. If the pivot point is broken or dulled, it can be touched up on the carpenter's oilstone. Since the adoption of light cards and a more elastic mode of suspension, there is less to fear from this cause.

Displaced Lubber-Line.

In case the elevated compass should be mounted North Country fashion—on a single pole, it is open to a special error. What seaman is there who has not seen a spruce topgallant-mast warp with a tropical sun, until the sheavehole looked over one bow or other, instead of right ahead? In the case of the pole compass, this twisting of the supporting spar has frequently occurred, and without doubt will occur again; and, as an inevitable consequence, the lubber-line is slued to the right or left of its proper place, perhaps to a serious extent. Against this latter source of error it is specially important to warn the navigator. To some it may appear needless to do so, but experience shows that misplaced lubber-lines have escaped detection for months, and in some cases years. The supporting spar of the Pole compass should therefore be fashioned out of wood not liable to twist (red pine and teak appear to be suitable), and, as an additional preventative, it should be well coated with *white* paint mixed with raw oil, and all rents carefully puttied up.

In one steamer, the brass band carrying the masthead compass

General caution as to lubber-lines.

had been slued out of position by the span of the after-hatch cargo derrick, and had remained so for several voyages. The error in the place of the lubber-line due to this cause was 7°. It has come under the writer's observation that numerous vessels have been nearly lost through want of attention to this highly important matter.

On taking command of a vessel about to proceed to sea, it should be one of the first duties of the captain to ascertain if the lubber point of his "Navigating compass" be exactly in a true fore-and-aft line. In one instance, where the error from this cause amounted to 6°, a steamer was all but run ashore on the Arklow Bank during misty weather; and the vessel actually completed her voyage to the Brazils and back without the master discovering what was the matter, though his courses, day after day, *must* have conveyed to his mind that there was a screw loose somewhere. In another instance a line-of-battle ship, in which the writer had the pleasure of serving, after shaping a course from Milford Haven to the Sevenstones, was found, at daybreak, to be miles outside the Scilly Islands. On investigation, the lubber-line of the "Navigating Compass" was discovered to be 5° to port of the midship-line.

Can it be true?

Co-efficient A.

Like a snake in the grass, this kind of error lies concealed, and cannot be dragged to light by azimuths or amplitudes, as these observations, unless treated in a mathematical manner, reveal only the errors of the *card*, and not those of the *bowl.** Pay strict attention, then, to this matter, as it is one of the "*important simplicities*" of navigation. When compass bowls are being painted inside, see therefore that the lubber-lines are not obliterated, and

* When the compass is so situated as to make it difficult to refer the lubber-line directly to the ship's head, and it is suspected to be badly placed, its error may be very closely determined:—*Carefully* ascertain the deviation on the four cardinal points, by comparison with the Standard or by the Pelorus, marking it + when easterly, and − when westerly. Add together those of a similar name. Take the difference between the two amounts thus found, retaining the sign of the greater, and divide it by 4. This remainder is known as the co-efficient A, and, in a well made compass, is due for the most part to a misplaced lubber-line. When the sign is +, the lubber-line should be moved to the right.

Deviation ship's head north − 12°		Head south + 2°
,, ,, east − 24°		,, west + 18°
− 36°		+ 20°
+ 20°		
4) − 16°		
Co-efficient A − 4°		

afterwards put in almost at random by some one ignorant of the mischief which may accrue from their carelessness. It is surely an easy task to paint close up to the lubber-line with a small camel-hair brush; and, to avoid mistakes in reshipping the bowl, when temporarily removed from the binnacle for any purpose, there should be only *one* lubber-line. This will prevent the possibility of reversal in the gimbals. Compass bowls are not unfrequently marked with *four* lubber-lines, but the use of the after one is not manifest. It should be painted over at the earliest possible moment. Those at the side may facilitate beam bearings.

More than 3 Lubber-Lines not advisable.

The reader must not imagine that "Pole Compasses" are the only ones liable to this defect, which has been known to exist in "Standard Compasses," "Steering Compasses," and even "Navigating Compasses." When detected, cover over the faulty line with two coats of thick white paint, and, with a black lead pencil, rule it carefully in again, in its proper place. Avoid making the line gouty, or too thick. Compass errors arising from mechanical defects already referred to are not unfrequently attributed to deviation. Flaws, punctures, or roughness of the jewelled cap, blunted or broken pivot-points, excessive weight in card and consequent insufficiency of the directive force, or the card not traversing freely in the bowl, are of the class of defects to be guarded against. If any of these exist, it can be detected by using a small magnet to pull the north point of the card a few degrees to the right or left—say a point—and noting where it will come again to rest when the magnet is withdrawn. Then in like manner pull the needle in the other direction, and if in both cases the card comes to rest at the same half degree, the compass is free from any of the above-named defects. But should the card not come to rest at the same place, then the further apart the two resting places are from each other, the greater is the defect from which it arises. Though unknown currents sometimes wreck ships, it is more often a current of *magnetism* than a current of *water*.

Mechanical defects.

It should be borne in mind by owners and others that a perfect compass is not the *only* want of the navigator. In fact, too much cannot be done by adopting improved nautical instruments of all kinds, so as to lessen the constant risk incidental to such an arduous, responsible, and hazardous profession.

CHAPTER IV.

THE MARINE CHRONOMETER.

The days of navigating by a carpenter's two-foot rule have gone by, and accurate time-keeping chronometers are a necessity of the "lightning age" in which we live. Without them the rapid ocean voyages, which are now of every-day occurrence, could not possibly be made, although the writer has heard it stated, in all seriousness, by non-nautical men, that the quick transit, from port to port, of the present ocean-express steamers, obviates the necessity for carrying chronometers!!! Such an idea, of course, could only be entertained by men entirely ignorant of the principles and requirements of navigation, and is scarcely in accordance with the steady increase in the establishment, all over the world, of Time-signals for the special use of shipping.

Chronometers versus Lunars.

It may be truly said that when chronometers came in, lunars went out—concerning the latter, something will appear in subsequent pages. Of late years not only has the chronometer been perfected in a high degree, as a reliable timekeeper, but its price has been reduced so low, by excessive and unhealthy competition, that to be without one, on any over-sea voyage, would be considered almost criminal negligence.

Time Signals.

In the principal ports, both at home and abroad, the process of rating is rendered quite simple by means of public time-signals. In some places the exact time is given by gun-fire, and at others by the dropping of a ball, or the instantaneous collapse of a cone. No matter what may be the method employed, the result is the same, and he who is now ignorant of the error and performance of his chronometers, cannot plead want of facilities for determining them.

The almost universal introduction, both by land and sea, of the electric telegraph, has lately been much used for the better determination of meridian distances.*

American expeditions.

In this work the American Government, since 1874, has taken a most prominent part, and has rivalled this country in going beyond its own domains to accomplish it. Under the direction of the Bureau of Navigation a selected party of trained officers of the U.S.N. has successfully carried unusually long chains of meridian distances, by the aid of the telegraph wire, to many important places in various parts of the world. These have been adopted as fundamental points whereby to fix others.

One of the first of these chains (1878–1879) embraced Greenwich—Lisbon—Madeira—St. Vincent—Pernambuco—Bahia—Rio de Janeiro—Monte Video—Buenos Ayres and Para, all of which stations were duly occupied by members of the party.

Lisbon longitude error.

Dr. Gould, Director of the Argentine National Observatory at Cordoba, had previously connected Buenos Ayres telegraphically with Cordoba, which, consequently, became the end of the chain. Strange to say, the longitude of the Observatory at Lisbon—though so near home—proved to be wrong more than 2′, shewing how unreliable Lunars, Moon culminations, &c., were for this work, notwithstanding the manifold resources of a well equipped Observatory. The other places were not half this amount in error.

In 1883–1884, another expedition, including most of the officers of the preceding one, carried a telegraphic chain from Vera Cruz through Guatemala—La Libertad—Salvador—Paita—Lima—Arica—Valparaiso and Cordoba, thus closing again upon the same terminal point, but by a totally different route. The two independent longitudes came out as follows:—

Cordoba—Extraordinary result !!

	H.	M.	S.
Cordoba Observatory by eastern chain - -	4	16	48·190 W.
" " western chain -	4	16	48·238 W.
Difference - - - -	0	0	0·048

The difference is barely the twentieth of a second, and when one considers the great length of each chain and the number of intermediate links, the result is little short of a miracle.

No uncertainty can, however, attach to meridian distances made by comparing previously regulated Time-keepers by means of land or submarine telegraph lines, when effected by skilled observers, and with proper precautions. Another remarkable instance of accordance is shewn by the Trans-Atlantic longitude measurements of the United States Coast Survey, where three

* When Sir G. B. Airy determined the Valentia-Greenwich distance he had thirty chronometers carried to and from the two stations more than twenty times. By the aid of the Pacific cable the San Francisco-Manila distance is found to be 7 hrs. 46 m. 18.761 secs.; and the time signal traversed the 7,847 nautical miles of the cable in 0.648 seconds. Easier and more accurate !

New York—Greenwich.

measurements between the meridian of Greenwich and that of the New York City Hall, made in different years and through different cables, differed by only *one-hundredth of a second of time!!*

It should be mentioned that, previous to the expeditions recorded as ending at Cordoba, the principal places in Central America, including Vera Cruz, had been connected telegraphically with Washington, so that the work of 1883–84 was but a continuation to the southward of a chain which had been dropped for a time.

In 1881—1882, more or less the same party of officers were employed fixing Yokohama—Nagasaki—Vladivostok—Shanghai—Amoy—Hong-Kong—Manila—Cape St. James—Singapore—Batavia, and Madras, this latter having been determined in 1876—1877, through Bombay, Aden, and Suez, by officers of the Great Trigonometrical Survey of India.

Vladivostok had been determined by Colonel Scharnhorst, in 1875, "By order of the Czar," and here we have the results of the two independent measurements:—

Russian and American Measurement.

	H.	M.	S.
Russian chain by way of Siberia, in 1875 - -	8	47	31·31
American chain by way of Madras, in 1881 - -	8	47	30·92
Difference one-third of a second - -	0	0	0·39

The Madras—Vladivostok chain was 6,450 miles in length; the other, St. Petersburg—Vladivostok, of about the same length, was effected by land telegraphs, and was very much the more difficult of the two.

Again in 1888–89–90, the American party carried out another chain between ports in Mexico, Central America, the West Indies, and on the north coast of South America.

Instrument in favour with Americans.

In all these American expeditions a specially designed combination of the Transit-instrument and Zenith-telescope was used for the determination of Latitude and local time. Time stars were selected as near the Zenith as possible, in case the Transit instrument should be ever so slightly out of the meridian. And for Latitude, from 10 to 20 pairs, north and south, were observed on each of three or four nights, weather permitting, so that there was every guarantee of accuracy in the results.

Observations of the Transit of Venus in 1874, and again in 1882, materially contributed to a more exact knowledge of selected stations, which until then had been known only approximately. In Australia and New Zealand the system of telegraphic determinations is being rapidly carried on. Paris—Greenwich was re-determined in 1902 with all imaginable care and refinement; so also was Montreal—Greenwich in 1892; in fact it may be asserted that there are now but few habitable spots on the globe of which the longitude is not known with abundant accuracy for navigational purposes.*

Three Chronometers a necessity. Vessels destined for long voyages should carry not fewer than three chronometers. If there are only two, and one becomes inaccurate, it is impossible to decide which is in error, whereas, with the former number, *and regular daily comparisons*, a tolerably correct judgment may be formed as to the going of each. The only advantage, therefore, in carrying a second chronometer lies in the fact of having a stand-by in the case of accident to one of them—such as the breaking of the mainspring, or other part of the delicate mechanism.

Much vibration injurious. Chronometers should, if possible, be kept in a part of the vessel free from jars or much continuous vibration; not in the after-end of a screw-steamer, nor in proximity to a steam-winch; neither should it be permitted to roll heavy bales or cases along the deck in their vicinity. If, however, this last cannot be avoided, it would be well to remove the chronometers from their outer cases for the time being, and bed them on soft feather pillows. On no account should they be slung in hammocks or cots whilst at sea, as it has been found to cause great irregularity in their performance.

In most steamers of modern build there is a chart-room on the upper deck, about the midships of the vessel, and this, for many reasons, is a good place. In the absence of a chart-room the Captain's own cabin is, of course, the next best place; and in this case it is well (in steamers) to have a fourth chronometer in the second officer's room, as a hack-watch for general use among the officers. If knocked about (so to speak), it will probably not go so well as the others, but this is immaterial, as a comparison can be made at convenience with the standard instrument; indeed it should be made every third or fourth day, and entered in a small book kept in the outer case of the hack-watch.

Hack Watch.

Chronometers are sometimes improperly stowed in one of the drawers of an ordinary set intended originally for clothing, &c. This is a very bad practice. To give them fair play, they should have a special mahogany box (as nearly air-tight as possible), fitted with a strong glass top, and divided by partitions, according to the number carried—each compartment being lined with green baize, and stuffed with best curled hair.

How to stow Chronometers.

* Paris—Greenwich re-determination was carried out by English and French observers. The result of the English showed that the longitude of Cassini's meridian is 9 m. 20.932 secs. E. of the Greenwich Transit Circle with a probable error of ± 0.006 secs. Montreal—Greenwich results showed that Montreal is 4 hrs. 54 mins. 18.62 secs. W. of Greenwich, with a probable error of ± 0.024 secs.

Details of fitting.

The chronometers should be removed from their own outer boxes, and the upper part of the double lid of the inner case dispensed with by taking the screws out of the hinges, so that the face of the instrument may be seen through the glass where the rate paper is usually kept. Being duly deposited in their several receptacles, all three can be seen through the double glass, and, as the opening of the lids for time-taking is rendered unnecessary, sudden fluctuations of temperature are thereby avoided.

The only occasion upon which the case requires to be touched is in the morning, to wind and compare, which should be done with closed doors.

Protecting cases.

In some first-class vessels, to protect the plate-glass top from the possibility of accidents, a substantial outer mahogany case is fitted over all. If this wise precaution be taken, the reader will understand that the chronometers are then in three distinct cases —first, their own, with upper portion of the double top removed; the second, with stuffed compartments and glass top; and the third, a strong outer shell entirely of hard wood. The steamships of the Pacific Steam Navigation Co., for example, have their time-keepers cared for in this way, and it is a plan well worthy of being generally adopted.

To those not accustomed to this arrangement, it may be considered cumbersome, and likely to occupy more space than can usually be afforded; but such is not really the fact, and too much pains cannot be taken to guard these valuable instruments from *draughts*, *damp*, and *dust*. In port, the chronometers having first been removed, the inner case should be well dried in the sun, and means taken to prevent cockroaches from making it their home—rent free. A little camphor will "evict" them.

Change of rate principally due to change of temperature.

Experience has fully demonstrated that any sudden alteration in the rate of a chronometer, which is otherwise fairly treated, *is more due to change of temperature* than any other cause. The great aim, therefore, of chronometer makers is so to adjust the relationship of the several parts of the balance, that their expansion and contraction may counteract the change of elasticity in the hairspring caused by change of temperature. Nevertheless, there are very few instruments so perfectly compensated, that they may be depended upon to preserve exactly the same rate, with a change of even 10° of temperature. How, then, can it be expected that a chronometer will continue its "shop rate" on a voyage extending over, say four months, during which the temperature has ranged between 40° and 85° Fahrenheit?

Shop rate unreliable.

Mr. Arthur E. Nevins, in a paper read before the Literary and Philosophical Society of Liverpool, says:—

"At present, chronometer makers allow no corrections upon the rate given for changes of temperature—and the universal practice at sea is to allow one rate for the voyage, whatever the temperature may be—apparently under the impression that an acknowledgment that such a correction is necessary, would be equivalent to acknowledging that the instrument was a defective one. The present method of compensating a marine chronometer is not absolutely perfect, but still leaves the rate of the watch subject to variations, owing to changes of temperature; and it is the infinite variety in amount and direction of these changes of rate in different watches, which causes the instruments on board a ship to differ from each other in the way they so frequently do. **Paper by Arthur E. Nevins.**

"Every good watch is, however, always affected in the same way, and to the same amount, every time that it is exposed to the same temperature, and the changes in watches follow a fixed law; and knowing, from observation, how they perform in certain temperatures, it is possible to calculate in what way they will perform in any other temperature to which they may be exposed. This law was discovered by the father of the late Mr. Hartnup, when Astronomer to the Mersey Docks and Harbour Board, as the result of testing upwards of two thousand watches which passed through his hands at the Liverpool Observatory—having been sent there by the makers to be tested and supplied with accurate rates. **Hartnup's Laws.**

"Mr. Hartnup's laws are the following:—

1st. Every chronometer goes fastest (*i.e.*, gains most or loses least) in some certain temperature, which has to be calculated for each chronometer from the rates that it makes in three fixed temperatures; the temperatures used at the Bidston Observatory for testing watches being 55°, 70°, and 85° Fahrenheit during winter, and 65°, 75°, and 85° in summer.

2nd. As the temperature varies, either increasing or decreasing from that in which the watch goes fastest, the watch goes slower; and its rate varies in the ratio of the square of the distance in degrees of temperature, from its maximum gaining temperature. For example—if a watch goes fastest in temperature 75°, it will go slower as the temperature either rises above or falls below 75°; and it will go slower by the same amount in any two temperatures that are the same distance from 75°: one being above and the other below, as in 65° and 85°—one being 10° below and the other 10° above 75°.

"The importance of a knowledge of these facts in using chronometers is easily seen.* Supposing a ship bound to the southward has three chronometers, *A*, *B*, and *C*, and they are all sent to the same chronometer maker to be rated. He gives the rate which these chronometers have kept while in his shop at a mean temperature of, say 60°. We will further suppose that *A* goes fastest in 60°, *B* in 70°, and *C* in 80°. As the ship gets into warmer weather in approaching the tropics, until she gets into a temperature of 80° or more, *A* gradually goes slower and slower all the time; *B* goes faster until the temperature rises to 70°, and then commences to lose, going slower and slower as the temperature increases more and more; and *C* goes faster all the time until it reaches 80°, which is about as high a steady temperature as will be attained for any length of time out at sea.

Chronometers may agree in misleading.

"Now, for these three chronometers to agree in showing the same longitude, it would be necessary for them all to keep steadily to the rates given them in England, or wherever they have been rated; but if they do not keep to these rates, the longitudes indicated by them will differ continually, and, by so doing, cause uncertainty and anxiety to the person using them.

"There is another case which may also occur, and which is really more important than the one above mentioned. It may happen, especially if all the chronometers on board are by the same maker, that they all go fastest in about the same temperature. Now, supposing that all these went fastest in, say 80°, and as in the above mentioned instance the rates of all of them were obtained in about 60° by the maker, they would all go steadily faster than the rates given as the weather got warmer, and would therefore all continue to indicate nearly, or exactly, corresponding longitudes, and these longitudes *would all be wrong;* but in this case the person using them would feel confidence in his position, and perhaps come to harm unexpectedly."

Advantage of temperature rates.

Lord Kelvin, in his "Lecture on Navigation," published by William Collins, Sons & Co., London & Glasgow, gave the following example, illustrative of the great value of Hartnup's method:—

"A certain chronometer, J. Bassnett & Son, No. 713, after being rated by Mr. Hartnup, was put on board the ship "Tenasserim," in Liverpool, December, 1873, for a voyage to Calcutta. . . . The ship sailed from Liverpool on the 21st of January, 1874, and on her voyage the chronometer was subjected to variations of

* Seamen, as a rule, used to entertain the erroneous idea that chronometers, like the commoner kinds of watches, always gained in cold and lost in hot weather.—*Lecky.*

temperature, ranging from 50° to 90°. The chronometer was tested by the Calcutta time-gun on the 26th of May. The time reckoned by it, with correction for temperature on Hartnup's plan, was found wrong by 8½ seconds. Another chronometer, similarly corrected by Mr. Hartnup's method, and from his rating, gave an error of only 3½ seconds. . . . The reckonings of Greenwich time from the two chronometers, according to the ordinary method, differed actually by 4 minutes 35 seconds, corresponding to 68¾ geographical miles* of error for the ship's place."

Apart from considerations of temperature, every new chronometer, possessing a well-hardened balance spring, has a tendency to gain gradually on its rate; that is to say, if the mean gaining rate for two months be five-tenths of a second per day, it will probably be seven-tenths or upwards in the next two months, and so on. The cause of this is involved in some mystery. It is supposed to be due to some molecular change in the material of the spring, which appears at first to strengthen it.† It is also perhaps produced by a thickening of the lubricating oil, which tends to diminish the amplitude of vibration of the balance, and thus cause an acceleration of the rate. A good chronometer, *after its newness has worn off*, will settle down to a steady rate, depending upon temperature. **Tendency of new Chronometers to gain on their rate.**

For the convenience of the navigator, rules have been formulated and tables compiled in connection with this subject of rating for temperature. The author has availed himself of Mr. Hartnup's kind permission to insert them in the Appendix.

When it is intended to take account of change of rate from changes of temperature, a maximum and minimum thermometer should be kept in the chronometer case, and the reading of their indices taken daily, and recorded in the chronometer journal at the time of comparing. In addition to the "shop" rate, which is from time of ship's return to port till she leaves again, the rate paper should shew the mean sea rate for the whole of the preceding voyage, viz., from time of leaving her home port till return to it. **Thermometers.**

In winding chronometers, care should be exercised to perform the operation *steadily*, without any jerky action which might endanger the chain. Most two-day watches require seven and a **Mode of winding Chronometers.**

* If reckoned on the equator.—*Lecky*.

† If there is no acceleration in a new chronometer, it is a fairly certain sign that the balance spring is soft, and the instrument will pretty surely prove to be a bad goer.

half turns of the key, the motion is always left-handed, and the last turn should be made slowly, but steadily, and *continued until the mechanism is felt to butt*, or, in other words, the chronometer should always be wound as far as it will go. A catch, acting at the proper moment, prevents undue stress being put upon the chain.

How to wind.

Cases have occurred where, through fear of causing injury, the officer having charge of the chronometers has neglected to take the *full* number of turns, and the consequence has been that, after a time, the chronometer has run down just before the usual time of winding. The winding index on the face should prevent such a mishap, nevertheless it has occurred.

A chronometer has to be turned "face down" to wind, and it must be eased back handsomely when the operation is completed, and not allowed to swing back with a jerk. This daily reversing of the watch is said to be a good thing, as it distributes the oil in the bearings.

Furthermore, chronometers should be wound punctually *at the same hour every day*, otherwise an unused part of the mainspring comes into action, which, if badly adjusted, is almost certain to produce an irregularity in the rate: attention to this also keeps them running on the same part of the chain, which is important. For similar reasons it has been found that eight-day chronometers do not preserve altogether the same rate throughout the entire week; that is to say, that (though other conditions may be the same) their daily rate towards the end of the week will not agree with their daily rate at the commencement of it; notwithstanding which, the *mean* rates of two consecutive weeks may agree exactly. To prevent this effect, an eight-day chronometer should be wound every day, the same as the others. On account also of the lightness of the balance, eight-day chronometers do not go so well on board steamers which suffer much vibration from their machinery.

Eight-day inferior to Two-day Chronometers.

If a chronometer should run down through neglect or other cause, on being wound up again it will probably not start till it has been quickly, *but not violently*, slued half round and back again. This is easily done by placing the instrument on the table and turning it horizontally between the hands.

When run down, what to do.

When a chronometer has run down, do not immediately wind it up and move the hands to the proper time, but wait till the Greenwich Mean Time by some other chronometer corresponds nearly with what the hands of the stopped one point to, *then* wind it up, and start it at the right instant. If this is neatly done, it is possible to set it going within a second or two of G.M.T.

Altering the hands of a chronometer does not necessarily hurt the instrument, but it is not *advisable* for any but a skilled person to do it; nor does it inevitably follow that, because a chronometer has been allowed to run down for a few hours, its rate will alter. The writer's experience of half a dozen instances goes to show that it will remain much as before.

Effect on after performance.

In such a delicate piece of mechanism, small and totally unlooked for causes will sometimes operate to derange the rate very considerably; for example, too much side-play in the gimbals will have this effect. A chronometer loosely hung may go with beautiful regularity *in port*, and astonish its owner by its after performance *at sea;* therefore, when the vessel is rolling considerably, the chronometers should be watched to see that they do not go over in the gimbals with a jerk; if they do, the gimbals must be tightened up until the jerk is no longer perceptible. On the other hand, do not jam the free movement of the instrument. Too little play is almost as bad as too much.

Side play in gimbals.

The writer on one occasion found his favourite time-keeper very wild in its rate, and for a long time he was at a loss to account for it. However, one day, when the vessel was going along in a heavy beam sea, he noticed the lateral play in the gimbals, and at once concluded that therein lay the cause of the trouble, which proved to be the case. When this was remedied (a very simple matter for a man whose fingers are not all thumbs), the chronometer resumed its former good behaviour.

Magnetisation of Balance.

On another occasion, whilst loading in the tiers at Pernambuco, the master of an iron barque, lying alongside, asked the writer to step on board, and look at a chronometer which he complained of as going in a most erratic manner ever since the vessel's arrival in port. After due examination of the works with the magnifying glass out of the sextant case, nothing could be discovered to account for the vagaries of the instrument. It was only when leaving the cabin that it occurred to the writer to ask what was in the square wooden box lying close against the chronometer complained of. The cat was let out of the bag when the master of the barque innocently explained that it was his Standard compass, which he had unshipped and placed below for greater security whilst in port. The powerful compass needles had by induction magnetized the steel portion of the balance, and ruined the going of the chronometer. Of late years another element of danger has been added to the list in the case of vessels lit by electricity. It is of the highest importance that the chronometers should be kept outside the radius of influence of the dynamos; say, *at least*, 50 or 60 feet away from them. For the convenience of engineers and others employed about electric plant, pocket watches have been made with springs and balances of Palladium, or some alloy, and termed "non-magnetic watches."

Care in selecting place for Chronometers.

For similar reasons great care should be taken not to stow the chronometers either close against an iron bulkhead, an iron ship's side, the upper or lower end of a vertical iron stanchion, or within 8 feet of compass compensating magnets. Nor should the chronometer case be screwed down to a table containing drawers which *might* be used to hold spare compass cards, or even, in exceptional cases, a horse-shoe magnet. Such things are often done unwittingly, and the ill-used chronometer condemned as a worthless instrument, when *in fact the blame rested entirely with its owner.*

Beware also of compass and chronometer makers who mix these instruments together in their shops as if they were so many pots and pans.

In many steamers the chart-room or captain's cabin is immediately abaft the fore wheelhouse, with which it communicates by a door or window. Should the chronometers happen to be stowed on a shelf or in a case on the *fore side* of this chart-room, they will probably be too near to the adjusting magnets of the wheelhouse compass.

As already stated, the mere fact of a bulkhead separating them won't stop the mischief in the slightest degree.

Avoid hidden iron.

Again, in many poop-decked steamers the Captain's cabin is at the fore-end of the poop, with windows looking out on the main deck, and most likely the Chief Officer occupies a similarly situated one on the opposite side. Now, it very often happens in steamers of the class alluded to, that to resist the effects of the sea, the transverse bulkhead forming the fore-end of the poop is constructed of iron, and sheathed with wood, to give it a finish. Of course it is lined inside also, and so the captain, unconscious of the mischief likely to ensue, may stow his chronometer close up against the concealed iron.

Chronometers should be kept away from iron almost as religiously as compasses. Captain E. J. Sharpe, Board of Trade Surveyor, points out that a chronometer should not be within 70 ft. of a dynamo. A point to remember!

In modern vessels, where iron is fast superseding wood in cabin as well as in deck fittings, it is sometimes exceedingly difficult to select a really good place for the time-keepers. Very often it is

"Hobson's choice;" nevertheless these matters should receive full consideration, *if the vessel is to go safely.* From the foregoing causes alone, the "Shore-rate" and the "Sea-rate" will seldom agree. It is advisable, therefore, that when practicable, chronometers should be rated on board, in the positions they are intended to occupy during the voyage. As before remarked, there are many facilities, such as time-guns and time-balls, for effecting it.

Necessity for comparison previous to Sailing.

Chronometers, when received on board previous to sailing, should be compared with each other, and the respective errors and rates applied to each, to note if they agree in their Greenwich Mean Time. This may seem a very needless precaution, but the propriety of it has twice been made apparent to the writer; and what has occurred to one may happen to others also.

Suppose that this matter of comparing be neglected, and that there should be only two chronometers on board; suppose further, that a wrong original error has been given with one of them (say, to the extent of one minute), and that the vessel proceeds to sea with dirty weather, and perhaps is several days out before getting sights; then, when the comparison is made, the navigator finds to his dismay that his chronometers differ from each other to the extent of a quarter of a degree of longitude. The Dead Reckoning cannot help him—indeed, if it were depended upon, it might just double the error. The only thing left to be done is to make some well-known point of land as soon as possible, take careful sights, and find out which chronometer is at fault.

If you intend passing close to an island for this purpose, do not go on the side which will bring the land between you and the sun, or *where will your horizon be?* Always think beforehand of the necessities of the case.

Instructive incident.

It so happened one fine day, when a friend was sailing for the West Coast of Africa, that the writer went on board to wish him "good luck." Being left for a time to his own devices in the skipper's cabin, he thought he would keep his hand in by comparing the chronometers which had just come on board. No sooner said than done: but to his amazement all three disagreed to the extent, not of seconds, but of *minutes.* Another try with the same result. This was getting serious, and the writer was getting flustered. Once more the rate papers were examined, and behold they had been placed in the wrong boxes!! When properly sorted, the chronometers proved in agreement.

As few merchant vessels carry more than three chronometers, that number will be adopted in treating of the proper mode of making the daily comparisons. For brevity, the several instruments should be known by letters, instead of the maker's numbers. The letter should be marked on a small slip of paper, and gummed conspicuously on the outside of chronometer case. For example, when standing facing them, the left-hand chronometer might be called *A*, the middle one *B*, and the right-hand one *C*—everything, when possible, being taken in its *natural order* or sequence.

Chronometer Journal.

An excellent form of chronometer journal is appended, and reference to it will shew that three chronometers enable three different comparisons to be made—the last being a check upon the others; for example, *A* is compared with *B*; *B* with *C*; and *A* with *C*. These comparisons should not be made simultaneously by three different observers, which is the common method on board ship; as it is *impossible* by it to attain the necessary accuracy. All the comparisons must be made by *one* individual, and a fortnight's practice, or at most a month's, will enable him to effect this to the *tenth* of a second. When we consider how small a portion of time is represented by such a minute division, it is not improbable that some may feel incredulous as to the practicability of estimating it correctly. But after the preliminary drill with the method about to be indicated, the doubters will be able to assure themselves that not only is it not impossible, but that with care it is sufficiently easy.

In all observatories on shore, the astronomer and his assistants are in the constant habit of splitting "tenths" with wonderful precision, and it may interest the reader to know that there are mechanical contrivances for dividing a second of time even into *one thousand parts*. As these do not enter into the practice of navigation, a description of them here would be out of place.

How to compare with precision.

To compare accurately, the operator, being quite alone, should close both windows and doors, so as to exclude noise. Having opened the *outer* cases, he should make ready with book and pencil for the first comparison, by opening the *inner* case of *A*, which will allow its ticking to be distinctly heard, whilst *B* is regarded through its glass lid.

It will be perceived by the reader that the operation is performed by the delicate relationship or sympathy existing between the eye and ear. *A* will be heard, and *B* will be seen.

Now, look steadily at *A*, and mentally count *with it*, assisting by a quick motion of the hand corresponding to every half-second beat. Having got well into the swing or rhythm of the beats,

DAILY RATES AND ERRORS OF CHRONOMETERS ON BOARD S.S. "BRITISH EMPIRE."

NOTE.—The + sign means fast or gaining; the — sign means slow or losing.

Date 1879.		A Accumulated Error.	A Daily Rate. Gaining.	A Daily Rate. Losing.	B Accumulated Error.	B Daily Rate. Gaining.	B Daily Rate. Losing.	C Accumulated Error.	C Daily Rate. Gaining.	C Daily Rate. Losing.	Temperature. 8 a.m.	Temperature. 2 p.m.	Temperature. 8 p.m.	Mean Daily Temp.	Reference to remarks on opposite page.
		m. s.	s. t.		m. s.		s. t.	m. s.		s. t.					
☉ May	18	+ 6 31·8	+ 1·6		− 11 44·3		− 3·1	− 12 43·5		− 2·0	65°	73°	70°	69°	*
☾ ,,	19	+ 6 33·4	+ 1·6		− 11 47·4		− 3·1	− 12 45·5		− 2·0	65°	72°	71°	69°	†
♂ ,,	20	+ 6 35·0	+ 1·6		− 11 50·5		− 3·1	− 12 47·5		− 2·0	60°	69°	67°	65°	‡
☿ ,,	21	+ 6 36·6	+ 1·6		− 11 53·6		− 3·1	− 12 49·5		− 2·0	59°	67°	63°	63°	§

DAILY COMPARISONS OF CHRONOMETERS.

Date 1879.		A compared with B. A	A compared with B. B	1st difference.	2nd difference.	B compared with C. B	B compared with C. C	1st difference.	2nd difference.	A compared with C. A	A compared with C. C	1st difference.	2nd difference.
		h. m. s.	h. m. s.	m. s.	s. t.	h. m. s.	h. m. s.	m. s.	s. t.	h. m. s.	h. m. s.	m. s.	s. t.
☉ May	18	2 31 00·0	2 12 39·4	18 20·6	——	2 15 00·0	2 14 5·4	0 54·6	——	2 36 00·0	2 16 44·8	19 15·2	——
☾ ,,	19	2 34 00·0	2 15 34·6	18 25·4	+ 4·8	2 18 00·0	2 17 6·5	0 53·5	− 1·1	2 39 00·0	2 19 41·2	19 18·8	+ 3·6
♂ ,,	20	2 00 00·0	1 41 30·0	18 30·0	+ 4·6	1 45 00·0	1 44 7·5	0 52·5	− 1·0	2 05 00·0	1 45 37·5	19 22·5	+ 3·7
☿ ,,	21	1 31 00·0	1 12 25·6	18 34·4	+ 4·4	1 14 00·0	1 13 8·3	0 51·7	− 0·8	1 35 00·0	1 15 33·8	19 26·2	+ 3·7

NOTE.—When *temperature rates* are used, the values in the daily rate columns will require to be altered as the temperature varies.

[In ordering this form the size must be increased to 14 in. × 8 in. over all. The divisional lines may be either red or black, according to purchaser's fancy. All the *left hand* pages are blank, to allow space for remarks.]

and decided to "stop," say, at 60s. (the even minute); remove the eye to B when A's second-hand has got to 52s. or 53s., keeping the sound of each half-beat still in your ears, and the hand going with it. When you have arrived *by sound* at 60s. (your chosen "stopping" point) the eye will enable you to decide upon the number of seconds and parts of a second shewn by B.

The other two comparisons will be made in a precisely similar manner. Of course in actual practice you note down beforehand the hour and even minute, by the *open* chronometer, at which you intend to "stop," or compare with the *closed* one; also, note the *hour* of the latter, and when proficient, the minute can also be noted, leaving only the seconds and tenths for the comparison.

The beginner, after a few trials by himself, will soon drop into the way of comparing with accuracy, and will congratulate himself upon being independent of outside aid, whenever he may wish to do so.

A likely suggestion. Another plan has been suggested, but as the writer has not tried it, he can only say it seems feasible. "Keep one hand free. At the beat of the second, or half-second, touch the table with the tip of the little finger, and rapidly pass along the other tips to the thumb, as a pianist would in playing a scale in the natural key. When, by practice, this can be effected in exactly half a second, then the touch of each finger will represent 0·1s."

Having compared all three chronometers, A with B, B with C, and A with C, accuracy of the result can, in a measure, be tested by comparing the interval between A and C, with the sum or difference, as the case may be, of the other two intervals, for example—(*vide Form of Chronometer Journal*) on ⊙ May 18th we have

	H.	M.	S.		H.	M.	S.		H.	M.	S.
Time by Chron. A	2	31	00·0	Chron. B	2	15	00·0	Chron. A	2	36	00·0
,, ,, B	2	12	39·4	,, C	2	14	5·4	,, C	2	16	44·8
Interval		18	20·6	Interval		0	54·6	Interval		19	15·2

Here 18m. 20·6s. added to 0m. 54·6s. gives 19m. 15·2s., equal to the interval between A and C, from which it may be assumed the comparisons have been accurately made, although, strictly speaking, such is by no means a certainty.

Chauvenet, in his valuable work on Spherical and Practical Astronomy, says—

Comparing Chronometers. "When two chronometers are compared which keep the same kind of time, and both of which beat half-seconds, it will mostly happen that the beats of the two instruments are not synchronous, but one will fall after the other by a certain fraction of a beat, which will be pretty nearly constant, and must be estimated by the ear. This estimate may be made within half a beat, or a quarter of a second, without difficulty; but it requires much practice to estimate the fraction within 0·1s. with certainty. But if a mean time or *Solar* chronometer is compared with a *Sidereal* chronometer, their difference may be obtained with ease within *one-twentieth* of a second. Since 1s. sidereal time is less than 1s. mean time, the beats of the Sidereal chronometer will not remain at a constant fraction behind those of the Solar chronometer, but will gradually gain on them, so that at certain times they will be coincident. **Solar and Sidereal Chronometers.**

"Now, if the comparison be made at the time this coincidence occurs, there will be no fraction for the ear to estimate, and the difference of the two instruments *at this time* will be obtained exactly. The only error will be that which arises from judging the beats to be in coincidence when they are really separate by a small fraction, and it is found that the ear will easily distinguish the beats as not synchronous so long as they differ by as much as 0·05s. (half-a-tenth); consequently, the comparison is accurately obtained within that quantity. Indeed, with practice it is obtained within 0·03s. or even 0·02s. Now, since 1s. sidereal time = 0·99727s. mean time, the Sidereal chronometer gains 0·00273s. on the Solar chronometer in 1s.; and therefore it gains 0·5s. in 183s., or very nearly 3m.; hence, once every three minutes the two chronometers will beat together. When this is about to occur, the observer begins to count the seconds of one chronometer, while he directs his eye to the other; when he no longer perceives any difference in the beats, he notes the corresponding half-seconds of the two instruments."

It follows that when two Solar chronometers are to be compared, it will in general be most accurately done by comparing each with a Sidereal chronometer by coincident beats, and afterwards reducing the comparisons. It is not likely that the ordinary navigator will possess a Sidereal chronometer, but the method is introduced here as likely to prove interesting, and to shew what *can* be done.

It has been already stated that chronometers should be compared daily, and with methodical regularity, and the proper entries made in a book known as the Chronometer Journal.* The writer **Chronometer Journal.**

* It is not uncommon to see the error of a chronometer marked opposite each day, on the margin of the page for the month, in the Nautical Almanac. This, in the

has for many years used the form given at page 57, and it is so self-explanatory that very little more is requisite. The "2nd difference" is merely the difference between the quantities for any two consecutive days in the column headed "1st difference." Thus, in the comparison of *A* with *B*, on May 18th the "1st difference" is 18m. 20·6s., and on May 19th is 18m. 25·4s.; the difference between these two is 4·8s., and, as the one chronometer is *gaining* and the other *losing*, it ought to be equal to the *sum* of their daily rates. As *A*'s rate is + 1·6s., and *B*'s — 3·1s., the sum 4·7s. shows a dissimilarity of only one-tenth of a second.

In the case of the "2nd difference" of *B* and *C* = 1·1s., as *both* these chronometers are *losing*, it ought to be equal to the *difference* of their daily rates, which happens exactly to be the case.

Of course, if two chronometers were *both gaining*, the "2nd difference" would in like manner be equal to the *difference* of their daily rates. But when their rates are going in *opposite* directions, the amount in the "2nd difference" column ought to be equal to their *sum*.

By scrutinizing the journal day by day, a fair judgment may be formed of how the chronometers are behaving. In the event of the "2nd difference" not agreeing with the daily rates, a careful analysis of the comparisons and record of temperatures, combined with a consideration of the respective merits of the instruments, may enable one to form a pretty just estimate of the value and direction of the change. For instance, if *A* does not agree with *B*, nor yet with *C*, but if *B* and *C* run well together, the inference that *A* has gone wrong would be a reasonable one, especially if *A* happened to be an old offender. In any case the navigator is put upon his guard, which is always something.

Rating for temperature at Bidston Observatory.

At the Bidston Observatory, near Liverpool, any master sailing out of the port can have his chronometer rated for temperature. The time requisite is six weeks, and on leaving, a paper accompanies the chronometer shewing its performance for every 5° of temperature between 45° and 95°; so that if the recommendation be attended to concerning the advisability of keeping a maximum and minimum thermometer in the case with the chronometers, and the rate altered to suit as often as necessary, the navigator can make sure of his Greenwich time within a few seconds, after a lapse of some months.* The Observatory *temperature rates*

estimation of some people, may be "handy," and in a sense it is so; but on a long voyage a properly kept "Journal" would look more ship-shape and business-like, quite apart from the question of utility.

* See Appendix A.

can be copied out on any of the left-hand pages of the journal, all of which are headed "Remarks," and ruled in faint blue lines.

In the specimen page of the Journal just given, it will be noticed that, for conciseness, it is only drawn up for four days; but in ordering one similar, the printer should be instructed to make the page deep enough to contain a week's work; also to leave an inch and a-half of space at the bottom for adding up and getting the *mean* of the "second differences" and temperatures, so as to adjust the rates in accordance with their indications. **Size of Journal**

Whenever the errors and rates have been ascertained afresh by observation, the proper entries corresponding to the given date should be made in *red* ink, so as to be easily found for reference. It will be found to simplify their application and facilitate calculations generally, if the errors are all recorded as either fast or slow of G.M.T., and not some one way and some the other. The writer prefers to have them all slow, as addition is easier than subtraction. To avoid having, in certain cases, the errors inconveniently large, the optician could be instructed to put them all slow, say anything between ten seconds and ten minutes, according to the direction of the rate. **Red ink entries.**

The winding and comparing ought to be invariably done by one person. The winding should be performed with care, and at the same speed on every occasion. This is important, because the maintaining power, which keeps the chronometer going while winding, varies, and, hence, if wound slowly, a chronometer may lose during the process. So long as this is regular, it does not affect the daily rate, as ascertained from observations at several day's interval; but if wound sometimes slowly and sometimes rapidly, error may be introduced. In large Mail Steamship Companies, the second officer is generally constituted the "Navigating officer," and, as such, has charge of the chronometers. It is his duty every morning to make *formal* report to the commander that they have been attended to. It would be easy to devise a plan suitable to any particular ship, whereby it would become impossible to neglect this important duty. In some men-of-war, the crew cannot be piped to their mid-day meal until the chronometers have been reported. In a merchant vessel it is usual to wind them in the morning. But whatever the time fixed upon, there should be a certain formality observed, which could not be omitted without sure and speedy detection.* **Winding and Comparing done by Navigating Officer.**

* A card, with the words "Wind Chronometers" printed or written on it, might be laid on the captain's plate by the steward every morning at breakfast time.

These sensitive instruments cannot receive too much care, for it is perfectly wonderful what apparently insignificant causes will sometimes affect them. Many years ago the writer owned two very valuable chronometers, which he highly prized, as their performance had been most satisfactory. On a passage home from the River Plate they both came to grief quite unexpectedly. Comparisons with a third time-keeper, kept in the second officer's room, and observations on shore at St. Vincent, shewed that they had taken up a prodigious losing rate, which grew day by day until on arrival at Liverpool it amounted to 20 and 25 seconds. Examination by the maker disclosed the annoying fact, that the springs and other steel portions of the works were thickly pitted with rust. Now, the Captain's room was situated directly over the main hold, which on that particular passage happened to be stowed full of salted hides. The coat of the mast, which came up through one corner of the cabin, had worked adrift on the side which was hidden from view, and the only inference to be drawn was, that the salt steam from the hold had penetrated to the mechanism, with the unfortunate result already mentioned. Though thoroughly cleaned and "re-sprung" they never went so well again.

Injury to Chronometers through springs rusting.

Jolting in a railway train, or a conveyance of any description, is liable to alter the steady going of a chronometer. The quick jerk of a boat smartly propelled by oars is still more likely to prove injurious. If, therefore, a chronometer has to be taken from one place to another in a pulling boat, it should be held free in the hand by the leather strap, and the men ordered to pull out of stroke; or, if the officer is afraid of being called a 'lubber,' and his boat's crew 'a pack of old women,' he can give the word to "pull easy." When carrying it by hand, avoid a rotatory movement, as this would very easily stop it till a similar movement set it going again, and so on. When travelling by train, place it on a pile of overcoats or railway rugs, in such a position that it will not fall. The *principal* cause, however, of a chronometer altering its rate when reasonable care has been taken of it, *is change of temperature.*

Causes likely to alter rate.

"Tripping."

In connection with this subject of rough carriage, the reader should know that a chronometer is exposed to a variety of mishaps which are very little understood except by "the trade."— For example, when the locking-spring of the escapement is too weak, it is possible for two teeth of the "'scape-wheel" (instead of only one) to pass the locking-pallet during a single vibration of the balance. This is called "tripping," and it is evident that in this way a chronometer may gain several seconds in a very short space of time, to the complete mystification of whoever has to do with it, unless he happens to be posted in respect of this peculiarity.

Mechanical possibilities

Tripping may occur also through a worn "'scape-wheel," the pallet-stone being badly set, or the several parts not being relatively in good adjustment.

On the other hand, should the locking-spring be too strong, the pallet will not get back sufficiently to release the "'scape-wheel," and the chronometer will not go at all, or if it does condescend to do so, will only move by fits and starts. Of course the maker would never let an instrument leave his hands in such a plight, but it is mentioned to shew the refinement of skill which is necessary in the manufacture and adjustment of such delicate mechanism.

Again—owing to the axis of the balance-wheel being but slender, a sudden jerk may bend it or break the extremely fine pivot-points, a misfortune which at once puts the chronometer "out of action" till the damage has been repaired.

Necessity for staying Chronometers previous to removal.

Before removing it from its outer case to carry it anywhere, a chronometer should be stayed, otherwise the instrument is apt to capsize in the gimbals, and when the inner case is next opened, to astonish the individual who has carried it by his finding the XII next to himself, instead of facing him on the far side as usual. Incredible as it may appear, the writer knew an officer, who, to his consternation, got a chronometer into this very same fix, and worse than all, neither knew how it happened, nor what to do to get it back into its original position.

Poising a Chronometer in the Gimbals

The poising of a chronometer in the gimbals has a very great influence on its rate. This can be tested on shore by staying the chronometer and keeping the case on its side for three or four days with the XII up. Next try it with the III, VI, and IX up, and it will be found that the rate in each case will be different to what it was when the chronometer had a horizontal position. The more expensive pocket watches are adjusted for any position, but marine chronometers are intended always to be kept strictly horizontal, with the face up.

Auxiliary Compensation

Experience has proved that chronometers, with the words "Auxiliary compensation" engraved upon their face, are not one whit better than those fitted with the ordinary balance. Without this knowledge, a purchaser of one of these instruments might fancy he was getting something "very special." Auxiliary bal-

These sensitive instruments cannot receive too much care, for it is perfectly wonderful what apparently insignificant causes will sometimes affect them. Many years ago the writer owned two very valuable chronometers, which he highly prized, as their performance had been most satisfactory. On a passage home from the River Plate they both came to grief quite unexpectedly. Comparisons with a third time-keeper, kept in the second officer's room, and observations on shore at St. Vincent, shewed that they had taken up a prodigious losing rate, which grew day by day until on arrival at Liverpool it amounted to 20 and 25 seconds. Examination by the maker disclosed the annoying fact, that the springs and other steel portions of the works were thickly pitted with rust. Now, the Captain's room was situated directly over the main hold, which on that particular passage happened to be stowed full of salted hides. The coat of the mast, which came up through one corner of the cabin, had worked adrift on the side which was hidden from view, and the only inference to be drawn was, that the salt steam from the hold had penetrated to the mechanism, with the unfortunate result already mentioned. Though thoroughly cleaned and "re-sprung" they never went so well again.

Injury to Chronometers through springs rusting.

Jolting in a railway train, or a conveyance of any description, is liable to alter the steady going of a chronometer. The quick jerk of a boat smartly propelled by oars is still more likely to prove injurious. If, therefore, a chronometer has to be taken from one place to another in a pulling boat, it should be held free in the hand by the leather strap, and the men ordered to pull out of stroke; or, if the officer is afraid of being called a 'lubber,' and his boat's crew 'a pack of old women,' he can give the word to "pull easy." When carrying it by hand, avoid a rotatory movement, as this would very easily stop it till a similar movement set it going again, and so on. When travelling by train, place it on a pile of overcoats or railway rugs, in such a position that it will not fall. The *principal* cause, however, of a chronometer altering its rate when reasonable care has been taken of it, *is change of temperature.*

Causes likely to alter rate.

"Tripping."

In connection with this subject of rough carriage, the reader should know that a chronometer is exposed to a variety of mishaps which are very little understood except by "the trade."— For example, when the locking-spring of the escapement is too weak, it is possible for two teeth of the "'scape-wheel" (instead of only one) to pass the locking-pallet during a single vibration of the balance. This is called "tripping," and it is evident that in this way a chronometer may gain several seconds in a very short space of time, to the complete mystification of whoever has to do with it, unless he happens to be posted in respect of this peculiarity.

Mechanical possibilities

Tripping may occur also through a worn "'scape-wheel," the pallet-stone being badly set, or the several parts not being relatively in good adjustment.

On the other hand, should the locking-spring be too strong, the pallet will not get back sufficiently to release the "'scape-wheel," and the chronometer will not go at all, or if it does condescend to do so, will only move by fits and starts. Of course the maker would never let an instrument leave his hands in such a plight, but it is mentioned to shew the refinement of skill which is necessary in the manufacture and adjustment of such delicate mechanism.

Again—owing to the axis of the balance-wheel being but slender, a sudden jerk may bend it or break the extremely fine pivot-points, a misfortune which at once puts the chronometer "out of action" till the damage has been repaired.

Necessity for staying Chronometers previous to removal.

Before removing it from its outer case to carry it anywhere, a chronometer should be stayed, otherwise the instrument is apt to capsize in the gimbals, and when the inner case is next opened, to astonish the individual who has carried it by his finding the XII next to himself, instead of facing him on the far side as usual. Incredible as it may appear, the writer knew an officer, who, to his consternation, got a chronometer into this very same fix, and worse than all, neither knew how it happened, nor what to do to get it back into its original position.

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Auxiliary Compensation

Experience has proved that chronometers, with the words "Auxiliary compensation" engraved upon their face, are not one whit better than those fitted with the ordinary balance. Without this knowledge, a purchaser of one of these instruments might fancy he was getting something "very special." Auxiliary balances, and some of the more complicated kinds—from their fragile and jointed construction—are specially liable to injury by shock. On this ground, if no other, the writer prefers the ordinary balance.

Cleaning Chronometers.

A caution will do no harm to those who, because an instrument is going pretty well, allow many years to pass without having it cleaned. It should be borne in mind that wear and tear is *constantly* going on; that the oil thickens, and eventually gets dried up; and that when this happens, the pivots of the moving parts must necessarily grind themselves away, and work differently to what is intended. Oil is one of the great difficulties in dealing with chronometers. No two makers are agreed as to the best oil for use. All confess to great difficulty. Not only is it difficult to get good oil that will remain perfectly fluid for some considerable time, but suitable oil, even if once made, cannot always be reproduced by the same processes. Not only does oil thicken, but its lubricating properties change by lapse of time: probably, from combination with oxygen, its chemical constitution changes. Temperature also has a decided effect upon oil, and it is found that its viscosity is much more altered by a change from 55° to 70° than by a change from 70° to 85°. Hence the rate of a chronometer under varying temperatures is intimately related to the behaviour, when heated, of the lubricating material employed. The oils least subject to thickening by time are some of the purified fish oils: their chief fault is an extreme fluidity and consequent liability to run away from the pivots. Never allow a chronometer to run longer than five years at the outside without giving it an overhauling at the hands of a first-rate workman. But if it is a new instrument, it should be looked at after a couple of years, and its rate 'closed.' It will then be at its best, and should continue so for years. This is so well known that the best makers never issue their chronometers till properly "seasoned."

Chronometer Makers and Chronometer Sellers.

Be *sure* that the man you give it to is a *chronometer*-maker, and not a *watch* or *clock*-maker. The latter may be very good as such, and yet understand very little about marine chronometers. Moreover, a large percentage of those who style themselves chronometer-*makers* are only chronometer-*sellers*, as the instruments are purchased by them at trade price from the wholesale manufacturers. If you know where to look for it, you can easily find the manufacturer's private mark.

Enough has been said to shew that chronometers are really almost like living organisms in the various manners in which they are affected by different influences: each has, in fact, its idiosyncrasy. On being removed from shore to ship, some become naturalised sooner than others, like human beings themselves; some again are less affected than their shipmates by the jar, sea-motion, and change of climate. To the scientifically inclined, their various constitutions and temperaments cannot fail to prove an interesting study. Except that it would scarcely be compatible with a work of this elementary description, it would be possible to illustrate the mode of utilising diagrams to exhibit curves of rate, temperature, and moisture. These, however, are more likely to find favour with philosophic investigators than with Practical Navigators.

How to obtain good Chronometers.

In concluding this chapter, it may not come amiss to those desirous of purchasing a reliable timekeeper to be told where to find it, and how to get it. Many of the best makers send instruments to the Greenwich, Kew, and Liverpool Observatories to be tested. At these institutions their performance is subjected to a rigorous cross-examination, and a careful record kept of their behaviour under various trying circumstances, and extending over several months. The Greenwich trial is exclusively for the Royal Navy; but at Bidston (Liverpool) and Kew the books are always courteously open for the inspection of those desirous of purchasing, and consequently, it should be an easy matter to select a good instrument from the many before you. When found, go at once to the maker, whoever he may be, and drive as good a bargain with him as you can. Do not grudge an extra pound or two; you will save it in sleep on a voyage.

The two best chronometers the writer ever had the good fortune to meet with were obtained by him in this manner at the Liverpool Observatory, Bidston Hill. They were selected from a large number, and, curiously enough, were by the *same* maker, and had *consecutive* numbers—a thing that might not happen again in one hundred years.*

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CHAPTER V.

THE SEXTANT.

The Sextant, of all astronomical instruments, is especially adapted to the purpose of the navigator, and for this reason it is incumbent upon him to render himself in every way familiar with its principle and make.

The multitude are sometimes puzzled to know why a sextant (derived from the Latin word *sextans*, signifying the *sixth* of a circle) should be thus named, when it is capable of measuring angles up to 120°, or the *third* of a circle.

Optical principle of construction.

If the possessor of one will but look at the arc, he will find out by his eye alone that, as a matter of fact, it consists only of the *sixth* part of a circle. The optical principle upon which the instrument is founded (that of double reflection), *permits of half a degree of the arc being numbered and considered as a whole degree.* Thus, in the sextant, what is really only an arc of 60°, is divided into 120 equal parts, *each of which does duty as a degree.*

The Octant, better known as Quadrant.

The instrument commonly known as a Quadrant is improperly so called. Though it is capable of measuring angles up to 90°, the arc only consists of the *eighth* part of a circle, and, in accordance with the rule adopted in the former case, it should be termed an Octant.* These terms, being at present opposed to each other,

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port (except under heavy repair) to permit of their chronometers undergoing the full temperature trial. Still, by watching slants, it can be done. It by no means follows that, because a man has made a chronometer which has been purchased as a good one by the Admiralty, all subsequent chronometers made by him will be *equally* good. From an examination of the published "Rates of Chronometers on trial, for purchase by the Board of Admiralty, at the Royal Observatory, Greenwich," it will be seen that the maker who has a chronometer first or second on the list in the order of merit, also not infrequently has another near the bottom of the same list. This shows the necessity of testing the chronometers themselves, irrespective of the names which they bear. There is a lot of luck about it.

* The original quadrant devised by John Davis, one of England's sterling seamen, in 1590, consisted of two arcs, which together made up 90 degrees, and was therefore an actual quadrant, as the name implies. It was generally known to seamen as the "back-staff," because the observer turned his back to the sun when taking an altitude; and it was superseded by Hadley's quadrant in 1731.

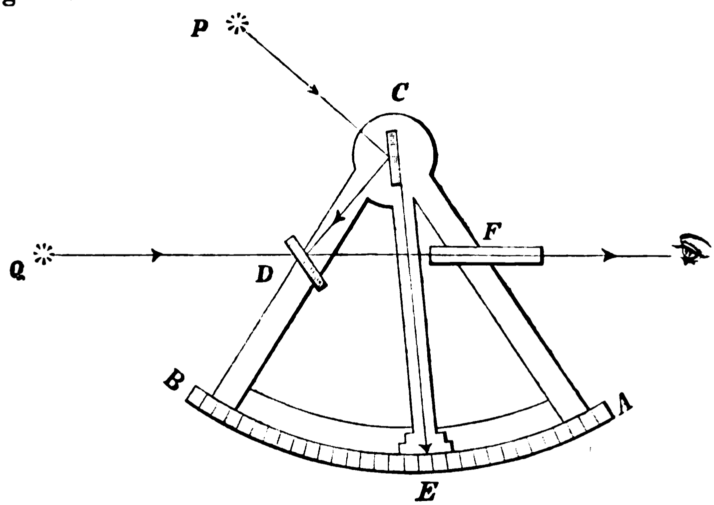
are a source of confusion, and might be rectified by abolishing the word Quadrant, and substituting Octant. Instruments capable of measuring angles up to 144° are in like manner termed Quintants. Quintants.

The optical principle upon which the Sextant is founded is thus announced:—

Statement of Optical Law governing Sextant.

"If a ray of light suffers two successive reflections in the same plane by two plane mirrors, the angle between the first and last direction of the ray is twice the angle of the mirrors."

The following illustration is taken from Herschel's Astronomy, page 117.*



Demonstration of law of double reflection.

Let AB be the limb or graduated arc of a portion of a circle 60° in extent, but divided into 120 equal parts. On the radius CB let a silvered plane glass D be fixed at right angles to the plane of the circle, and on the moveable radius CE let another such silvered glass C be fixed.

The horizon glass D is permanently fixed parallel to AC, and only one-half of it is silvered, the other half allowing objects to be seen through it.

The index glass C is wholly silvered, and its plane is parallel to the length of the moveable radius CE, at the extremity (E) of which a vernier is placed to read off the divisions of the limb.

On the radius AC is set a telescope F, through which any object Q may be seen by *direct* rays which pass through the unsilvered portion of the glass D, while another object P is seen through the same telescope by rays which, after reflection at C, have been

* Published by Longmans & Co.

thrown upon the silvered part of *D*, and are thence directed by a second reflection into the telescope.

The two images so formed will both be seen in the field of view at once, and by moving the radius *CE*, will (if the reflectors be truly perpendicular to the plane of the circle) meet and pass over without obliterating each other.

The motion, however, is arrested when they meet, and at this point the angle included between the direction *CP* of one object, and *FQ* of the other, is twice the angle *ECA*, included between the fixed and moveable radii *CA*, *CE*.

Now the graduations of the limb being purposely made only *half* as distant as would correspond to degrees, the arc *AE*, when read off as if the graduations were *whole* degrees, will in fact read *double* its *real* amount, and therefore the numbers so read off will express, *not* the angle *ECA*, but its *double*, which is the *actual* angle subtended by the objects.*

Peculiarity in human eye.

Though epitomes mostly explain how to *read* the vernier, they neglect to explain the peculiarity in the human eye which gave origin to its invention.† The value of the vernier as a means of reading minute divisions depends upon the fact that, when they are within a certain degree of closeness, the eye cannot separate a series of parallel lines lying side by side, there being a point for all vision where such lines appear to mix with the ground upon which they are drawn, and thus form a tint: therefore it would be difficult to say, unless under extreme magnification, to which one of these lines the index arrow pointed. Further than this, it would be quite impossible to graduate the arc of a sextant to the required degree of minuteness. Taking a sextant of 8-inch radius divided to 10″, the space between each line on the arc would be equal to ·00019 of an inch, and the line itself would almost have to conform to the geometrical definition of "length without breadth," conditions, in either case, clearly impracticable.

Spacing of divisions

Now it is a recognised fact that so long as the eye can see a single straight line *distinctly*, it can detect any break in its continuity. The divisions on the arc of an 8-inch sextant are easily discernible under the magnifier. In modern instruments each degree is divided by strokes into six equal parts, each stroke

* It can be easily demonstrated that the angle *ECA*, between zero of the arc and zero of the Index vernier, is equal to the angle of the mirrors *CED*, which is all that is wanted to establish the truth of the theorem given above.

† Sometimes called a "Nonius," from Peter Nonius, who, about the middle of the 16th century, first enunciated its principle and application in a somewhat laboured and crude form, which was simplified by Pierre Vernier in 1631.

therefore represents 10′, and the space between each stroke—supposing the stroke to be infinitely thin—is ·0116 of an inch, which is well within the power of a dividing engine. Under but weak magnification, this space, tiny as it is, appears *perfectly* clear and distinct. So far the arc. In the form known as the "extended" vernier, the divisions are nearly double the distance apart of those on the arc, and are therefore even more clear and distinct, so that, when any one of the vernier lines coincides exactly with a line on the arc, the fact is easily observable, and this particular line may be taken as giving the true value of the reading. The principle of the vernier is such that, in a well cut sextant, only one at a time of the vernier lines can possibly coincide with one on the arc *when the zero line or arrow of the vernier is itself out of coincidence.* **Spacing of divisions.**

But when the zero line is *in* coincidence, then the terminal line of the vernier must also be in coincidence, or the sextant is badly cut. At such times as a line on the vernier coincides with one on the arc, all the others appear broken or discontinuous, becoming more so in proportion to their distance right or left of the reading. In badly divided instruments it may happen that two or even three lines of the vernier may appear in coincidence and puzzle the observer as to which he should accept. Such a sextant is not worth having, except for rouse-about work, such as angles of land, &c. It is found that a line, as fine as it can be clearly seen, will appear broken in its end-to-end continuity with another equally fine line, if at their point of meeting the lateral displacement should amount to a quarter of the thickness of either line. The vernier permits of this being readily carried out in practice, and affords a method of arriving at small readings which cannot be excelled. To obtain the full benefit of it, the divisions, both of arc and vernier, must be accurately spaced, and sharply, though finely, cut. Instruments for the determination of angular measure are not all alike in their graduation, so on attempting to read off a new instrument it is first necessary to ascertain by inspection the law of that particular vernier. To explain the *principle* of the vernier would be altogether too tedious, even if successful. **Testing divisions.**

The navigator who takes a proper pride in his work should possess a *first-class* Sextant or Quintant, and a *good* Octant. The latter is fully equal to everyday work *in the broad ocean,*—for example, during the winter months in the North Atlantic. The delicate exactness of the other instrument is quite thrown **Respective fitness of Quintant and Octant.**

away when one can only get flying shots at the horizon, from the crest of a 60-feet wave. Showers of salt spray, with the chance of an occasional knock, certainly seem less suited to the sextant than to its hardier and more humble relative.

On the other hand, for fine weather use, for stars, lunars, observations on shore with artificial horizon, and for fixing the ship's position in the neighbourhood of land by angles, the Quintant is undoubtedly the proper instrument.

Angles of the land for "fixing" purposes are not required to seconds, nor even to minutes: ordinarily, it is sufficient if the error does not exceed the sixth of a degree (10′); the only reason, therefore, for mentioning the Quintant in this connection, is that occasionally one or both of the angles may be so large as to be beyond the range of the Octant.*

Care in purchasing Sextant.

A *good* Quintant or Sextant costs money—*and is worth it.* Unless you are a fair judge of one, it is as easy to be deceived in purchasing a sextant as in buying a horse. The market is glutted with sextants *made for sale.* Every pawnbroker's window in a seaport town is half full of them. Some vendors even hold out the inducement in large type that their instruments are "free from error." If, indeed, by accident such should happen to be the case at the moment of purchase, it need not be a matter of speculation how long they will remain so. The thing is absurd, and might with equal justice be said of a chronometer or a patent log. At the Aberdeen meeting of the British Association in 1885 (four years after this was written), the late Mr. G. M. Whipple, B.Sc., F.R.A.S., the then Superintendent of Kew Observatory, read a paper "On the Errors of First-class Sextants, as determined from the Records of the Verification Department at the Kew Observatory.".

He pointed out that the instruments were sometimes inferior, and it was generally observed that though good sextants could be had if a proper price were paid for them, there was a large number of "cheap and nasty" instruments in the market, and in fact that the trade had partly drifted into improper hands, the manufacture of such instruments having become a commercial instead of a scientific matter.

Points to be noted.

The intending purchaser should spend half-an-hour or so in satisfying himself as to the following points. Avoid a sextant of less than 8 inches radius. The divisions of a smaller instrument are difficult to read, especially at night, and are not likely to be

* This difficulty has recently been overcome (*see* page 157).

near so accurately cut. A 6 or 7-inch sextant is of course somewhat lighter to handle, but sailors are not women; and a certain amount of weight gives steadiness, especially in breezy weather. The writer's instrument is a 10-inch "pillar," by Troughton, divided on platinum.

"Pillar" sextant.

The old recommendation was to give the preference to a "pillar" sextant: in its day it was without doubt *the* correct thing, if only because the make was confined to the very best instruments, and therefore a sort of guarantee of good workmanship. But the world moves on, knowledge increases, good things are superseded by better, so farewell to the "pillar."

Rigidity.

An indispensable condition in a sextant is rigidity; flexure is fatal, and, though the design varies considerably according to taste, all makers now adopt the principle of putting the stiffening on its edge; that is to say, the framework or webbing, between the two external arms at the ends of the arc, is much deeper than it is wide. Again, it is necessary to select a material capable of undergoing considerable thermal changes with the least possible amount of deformation, permanent or otherwise.

Expansion and contraction.

Usually the casting is of gun-metal, or something approaching it; quite recently, however, some sextants have been made of Aluminium, on the score of lightness; but this latter, as shewn above, is not an unmixed blessing. In point of strength and liability to expansion there is not much between them, so in these respects one is as suitable as the other. Talking of expansion, sextants should not be laid down on a skylight under a broiling tropical sun. The divisions are beautifully fine, and supposing them to have been cut in the ordinary temperature of a workshop—say 60°—it does not need much gumption to see that when the temperature runs up to, say 140° or 150° *in the sun*, there must occur a very considerable change in the limb and instrument generally. Under the immense strain the weakest part will give, and probably result in permanent distortion. Like the captain's gharry hire—you may not *see* it—but it's there all the same.

Brains are given to us for use.

Further, if we suppose the arc to be of platinum and the framework to be of gun-metal, or some similar alloy, the limb will *try* to tear away from the narrow strip of inlaid metal, owing to their vastly different rates of expansion. Therefore, if you cherish your sextant as you should do, and expect it to be faithful to its trust, you, in your turn, must treat it with some degree of intelligent consideration.

To test the arc, set the zero of the vernier very carefully at various divisions along the arc, and then note if the left hand division of the vernier coincides exactly with one on the arc. If the latter is correctly graduated, it should coincide in *every instance.* Cheap sextants won't stand this test.

Vernier and false readings. Examine the vernier, to see that its feather edge lies perfectly flush with the face of the arc, otherwise, by a slight side movement of the eye to the right or left of a point exactly vertical to where the divisions "cut," a false reading is obtained. This is very likely to occur at night, when reading off by the light from a swinging lamp.

An extended vernier, by which is meant a vernier whose divisions are twice the distance apart of those on the arc, is now considered to be "the correct thing," and is a great help to accurate reading.

A steel tangent-screw will not only last longer, but will work more evenly than a brass one.

Telescopic power. One of the eye-pieces of the inverting telescope should have a tolerably high magnifying power—say 14 or 15 diameters, as contacts of the sun's limbs in observations with the Artificial Horizon are easier made in proportion to the size of the suns.

To do away with the annoying and error-producing glare so often witnessed on the sea horizon, till the sun gets above 50° or so, Mr. T. Mackenzie, of the R.M.S. *Moselle,* inserted a Nicol's prism close up against the object-glass side of the diaphragm of his inverting telescope. This was so placed that when the telescope was screwed home in its collar, the polarising plane of the prism would be parallel to the plane of the sextant, and consequently perpendicular to the plane of the horizon when making observations. By this device the intense glare of light from the horizon is totally refracted out of the prism, and only the 'extraordinary' ray transmitted to the eye. The horizon is rendered comparatively dark, and clearly defined, being free, moreover, from the displacement which coloured shades, wanting in parallelism of their faces, always give.

Mr. Mackenzie, in a communication to the Royal Astronomical Society, stated that it fulfilled all he expected from it. One eye-piece might be so fitted at very little cost.

"Interrupted thread." Cary, of the Strand, who, by the way, makes a specialty in what he calls his "Edge-Bar" Sextant, has applied to sextant telescopes the principle of the "interrupted thread," hitherto only used for the breech mechanism of heavy guns. Half a turn suffices to ship or unship the telescope without detracting from its security. This plan saves time, temper, and fumbling.

In case your sextant is not already fitted with a good "star telescope," by all means get one. It will pick out the horizon on a dark night when the unassisted eye would be in error several minutes of arc. Some men, after getting the star roughly down near the horizon, hold their sextant in one hand, and a binocular close up to it with the other, and then endeavour to perfect the contact. This is a bad plan, and to convince any one that it is so, let them try it with the sun in broad day-light. It is true the horizon is rendered much more distinct, but with every motion of the binocular the object will dance about—sometimes above the horizon, and sometimes below it.

Star Telescope

Improper to use Binoculars.

To ensure a correct altitude, the line of sight of the telescope used *must be parallel* to the plane of the instrument; this is termed "the line of collimation," and it is abundantly evident that one cannot guarantee to effect this by guess-work, in the dark, with a pair of night-glasses held loosely in the hand. In Table 54 of Raper's Epitome will be found the amount of error corresponding to the altitude of the body observed, and the angle the telescope makes with the plane of the sextant.*

It is also well to know that the error, due to the optical axis of the binocular not being held strictly parallel to the plane of the instrument, *always* lies in the direction of making the altitude *too great*, so that those who incline to this mode of observing would do well to make allowance in accordance with the rule.

The index and horizon glass screens should be of neutral tint, instead of red, yellow, green, &c. The various depths of shade correspond to the *thickness* of the glass. The coloured screens which screw on to the eye end of the telescopes should also be neutral tint.

Colour of Index and Horizon Screens.

The front and back faces of the index glass ought to be strictly parallel to each other. This can be tested by placing the sextants on a table or other steady support, and looking obliquely into the mirror at the reflection of some distant object. The image should have sharp and well-defined edges. If they are at all blurred or indistinct, the glass is more or less prismatic.

Test for parallelism of back & front face of Mirrors

Another method of determining this is to examine the reflected image of a star with the index set to a reading of 120° or thereabouts. The index glass reflects from its outer as well as from its

* *Vide* Appendix C.

silvered face, though in a less degree. If the faces are parallel, the rays from the star reflected from the two faces will be parallel after leaving the glass; they will therefore be converged to the same focus in the telescope, and produce but a single image. But if the glass is prismatic, there will be two images, a fainter image superimposed upon the stronger one, and not quite coincident with it. The star, therefore, will not shew as a well defined point without sensible magnitude, which it ought to do if the glass were perfect.

Want of parallelism of the *horizon-glass* is of less consequence. It affects all angles (the index correction included) by the same quantity, and therefore produces no error in the results.

Test for Coloured Screens.

Next, examine the coloured screens for the same defect. If their faces are not ground parallel, the sextant will have a different index error for each pair or combination of screens. Detection in this case is easy. Make an accurate contact of the sun's limbs, on or off the arc, as the case may be, using with the telescope one of the coloured screens belonging to it.* Then, after discarding this screen from the telescope, turn down suitable combinations of the index and horizon screens, and see if the contact still remains perfect. If not, make it so, and the difference between the first and last reading will be the error of that pair of screens, and so on for the remainder.

Screens fitted to reverse.

In some special sextants the screens are so arranged as to admit of being instantaneously reversed; therefore, to eliminate the errors of these glasses, it is only necessary to take one half of a set of observations with one position of the screens, and the other half with the reverse position.

Imperfection in the coloured shade, just alluded to, which ships on to the eye-piece of the telescope, is of no particular importance, as the object and reflected image are affected alike, and the angle between them remains unchanged.

The prismatic sextants, above referred to, differ from the ordinary sextant, not only in their general construction, but in their capabilities, for they can measure angles up to 180° from the ordinary sextant, not only in their general construction, but in their capabilities, for they can measure angles up to 180° with perfect accuracy. In dealing with large angles there is no confusion or multiplicity of images, and objects appear distinct

* In the best instruments it is now usual to fit eye-pieces with a revolving disc, so that by a simple movement of the finger you can interpose screens of three different intensities, or do without them if necessary. This saves an awful lot of bother from passing clouds when taking observations with the artificial horizon.

and well defined in every position of the index glass. At all times, both the reflected and direct images are much better defined than is usual in other instruments.

Finally, the arc in a high class sextant should be of platinum or gold. A good combination is a platinum arc and a gold vernier; the contrast seems to make reading easier. The gold would be too soft if finer than 15 carat. To divide platinum satisfactorily a diamond-pointed tool must be employed; steel is found to drag the edges of the cuts and spoil their sharpness. It is in dispensable that the divisions, both of the arc and the vernier, should look fine and clean cut when viewed under the microscope. To *ensure* the best of everything, you must purchase from a maker of repute, and not grudge the cost.

Index error.

The index error should be found before and after all important observations. At night it can be determined with great facility by means of a star of the 2nd or 3rd magnitude. Set the vernier a few minutes one side or other of zero, screw in the telescope and direct it to a suitable star, and by means of the slow-motion-screw bring the images exactly in one. The reading will be the index error, subtractive if *on* the arc, and additive if *off* the arc. As a star of the 3rd magnitude is a mere speck of light, the method admits of great accuracy, *and will be found much less fatiguing to the eye than a similar observation of the sun.* The reflected image should pass exactly over the direct one; if it passes on either side of it, the horizon-glass is not perpendicular to the plane of the instrument, and wants attending to.

Index error by Sea Horizon.

It is a common practice to ascertain the index error by the sea horizon in a manner similar to the foregoing, and the method is a correct one; but it will not work on shore where the top of some straight and level object is employed to represent the horizon, unless the object so selected be *at least* half a mile distant. The index and horizon-glasses would subtend a sensible angle at the place of an object *within* that distance; and, though the glasses should be parallel to each other, coincidence would not be established between the reflected and true images.

Beware, therefore, of self-styled opticians who are occasionally to be seen at their shop doors adjusting sextants by the roof of the house opposite. In doing so they betray their own ignorance

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as well as their customer's confidence. Some one, with more humour than reverence, has suggested the word "Shoptician" as a fitting title for such men. Perhaps it is.

Some officers have an idea that a large Horizon-glass is an advantage, as it gives more 'field.' This is not the case. The amount of 'field' is regulated by the Index-mirror, and so long as the Horizon-glass reflects the whole of the Index-mirror it does all that is required. For *astronomical* purposes the mirrors in ordinary use are ample; but for measurement of points along the coast it is an undoubted advantage to have a large Index-mirror, to take in more of the landscape, and so facilitate the finding of the particular object from which the angle is to be measured.

Adjustments.

The four adjustments, and the means of making them, are so lucidly explained in the various Epitomes of navigation, and they are so simple in themselves, that it is quite unnecessary to waste space in treating of them here; as a rule, a *good* instrument, if carefully nursed, will remain in sufficiently close adjustment for an indefinite time. Some officers are never satisfied unless they are tinkering at the adjustment of their sextants, and, as a consequence, the screws work slack, and the sextant does not remain correct for 24 hours on a stretch—in fact, the more it is meddled with, the worse it gets.

Raper is very emphatic on this matter. He says:—

Raper's advice as to Adjustments.

"The adjusting screws are *never to be touched except from necessity*, and then with the greatest possible caution. Particular attention is called to this point, because it is a common failing of 'over handy gentlemen' (to use Troughton's language) to 'torment' their instruments. It is better that error should exist, provided it is allowed for nearly, than that mischief should ensue to the instrument from ignorant attempts at a perfect adjustment; and the skilful observer, instead of implicitly depending upon the supposed perfection of his instrument, will endeavour to avail himself of those cases in which errors, if they exist, will destroy each other."

If of a mechanical turn, however, and really anxious to learn the way a sextant is put together, first-rate practice can be had with a cheap second-hand one, which can be taken to pieces with impunity, put together again, and experimented upon in a variety of interesting ways: for instance, it would be instructive to determine by reversal, the error, if any, due to a prismatic form of the index and other glasses. The reflectors might also be resilvered according to Belcher's method, as described in the Sailor's Pocket Book.

Do not stow your sextant case in a drawer, or on an out-of-the-way shelf, from which a sudden jerk of the vessel might send it flying. Rather, get a brass band $\frac{3}{16}$ of an inch thick, and $\frac{3}{4}$ of an inch broad. Let it be bevelled to fit three sides of the box a little better than half way up. Cover this with coloured flannel or wash leather, and screw it to the bulkhead in such a manner that the sextant case can be dropped into it, and remain secure in any weather, and at the same time be handy for use. **Mode of stowing Sextant Case.**

A square sextant case is in all respects an improvement on the old shape: it can be secured to the bulkhead pretty much in the same way as the other. Fit a brass handle on the keyhole side to carry it by.

For convenience of reference, in case of a suspected mistake in reading off, the lid of the sextant case should be fitted so that it will close with the index clamped at any part of the arc. **Mode of fitting Sextant Case.**

Further, the receptacles for the telescopes should be long enough to allow of them being put into the case when set at focus. This is uncommonly handy when you are in a hurry. In an extra receptacle you should keep a nice soft camel-hair brush, about the size of the tip of your little finger; it is most useful for brushing off dust, &c.

Never put your sextant away without *lightly* wiping the glasses with a clean piece of fine soft chamois leather. Do not use your pocket handkerchief for this purpose. Moisture allowed to remain on the mirrors will soon impair the silvering, and render star observations difficult. The chamois leather should be washed with soap and water when requisite, and rubbed perfectly soft with the hand after being well dried. If pressure be applied to the glasses in cleaning them, their adjustment will be disturbed. So be careful. **Index and Horizon Mirrors suffer by damp**

A little sweet oil and lamp-black occasionally smeared over the arc and lightly wiped off again, does good, and makes it easier to read. You may also, now and again, very sparingly oil the tangent screw, as well as the *back* of the *arc*, and the *front* of the *vernier-plate, where in each case the springs traverse.* Rub off the superfluous oil with another piece of chamois leather kept specially for the purpose. Do not let the two pieces come near each other, as oil or grease would not suit the mirrors.

When you send your sextant to an optician to have the glasses resilvered, instruct him not to polish the arc. The ordinary **Arc not to be polished.**

compass-maker, thinking to please you, is *sure* to do this, to the great detriment of the instrument, unless you give him *most positive* instructions to the contrary. Before finally deciding to purchase an expensive sextant or quintant, arrange with the maker to have it tested, and its errors determined and tabulated at the National Physical Laboratory. The fee is a trifling one —only five shillings, exclusive of carriage to and fro. Any person ordering instruments from opticians may direct them to be previously forwarded there for verification. Address— The Director, National Physical Laboratory, Teddington. In these pages it has been shewn how to test the mirrors, also the parallelism of the shades, but to test the centering errors is practically beyond the power of the navigator. If a man of infinite resolve, he may succeed, it is true, by vexing his soul with a series of astronomical observations of a painfully tedious character. Much better to pack the instrument off to Kew, where, by a system of collimators, the centering errors are determined for every 15° of arc both quickly and accurately. Please note that 'centering error' and 'index error' are quite independent of each other. Each must be applied in accordance with its own sign + or —.

Instruments can be tested at Kew Observatory.

Index and centering errors.

A few more hints *re* sextant management. In reading off, whether by day or night, do not hold it *sideways* to the light. Let the light come straight along the index-bar to the vernier; and to tone down excessive glare, a *moveable* ground glass screen should be fitted in front of the vernier. Neglect of these things may cause an error in the reading of two or three minutes. Cary has a neat arrangement by which to read off at night: a small dry-cell battery actuates a tiny incandescent lamp. This latter fits into a socket in the carrier of the "reader," and shews a light for two minutes. The current must then be switched off for an equal time; but in practice this is unnecessary, as reading off will not occupy more than half that time, and during the next observation the lamp is recovering its power. The cost is £3 10s.

Electric lamp to read off by.

The reading microscope is sometimes called the magnifier or "reader." Now, it is no use for the mathematician and mechanician to expend their energies in the production of a refined instrument if the means of reading its indications are of an inferior character. It would obviously be labour lost. The strength of a chain is measured by the strength of its weakest link. Therefore it is to the magnifier we look to give us truthfully the final result to which the various parts of the instrument have jointly contributed. The magnifier has a duty to perform.

In traversing the vernier it is important, for delicate reading, that its sweep should have the same radius as the arc itself. To fulfil this condition, it is clear that it should rotate on the same centre as the index-bar. This is not possible in the ordinary sextant, but Messrs. Hughes, of Fenchurch Street, have brought out an 'improved Quintant' having the legs in front and the index and horizon glasses at the back, which easily permits of it. The 'reader' itself is so arranged that its focus can be altered without danger of bending the carrier. The legs being in front are a great convenience in setting down or taking up the instrument. The makers claim that, owing to the setting of the mirrors, and the index-bar having freer range, an unusually large angle can be measured. Here it may be said that after 140° the relation between the index and horizon glasses in an *ordinary* sextant becomes such as to render observations impracticable. Messrs. Hughes achieve their object by placing the telescope holder close up under the index-mirror, and shifting the horizon-glass to the extreme end of the arc, so as to make the angle formed by the centre line passing through both mirrors, and that passing through the Horizon-glass and axis of the Telescope, as *acute* as possible. This instrument, therefore, is specially adapted to Artificial Horizon work and measurement of large angles generally. It has many points to recommend it, and is altogether a revelation and a revolution in Quintants.

To conclude the chapter. There is a proverb that "You should never lend to any one your horse, your gun, or your dog." It applies also to the sextant, 'only more so.' Bear it in mind, dear boy.

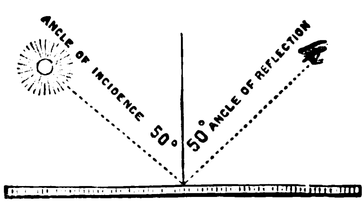
CHAPTER VI.

THE ARTIFICIAL AND SEA HORIZONS.

There are many varieties of the Artificial Horizon for shore use; but results, not to be surpassed for accuracy, are obtainable with the ordinary kind, in which a flat and shallow cast-iron trough, containing pure quicksilver, is protected from the wind by an angular glass roof. This form is not quite so compact and portable (or so expensive) as some others, but circumstances alter cases; and the Navigator, unlike the explorer, has not, for an indefinite period, to trudge along under the weight of his own gear with the thermometer at roasting temperature.

Law upon which it is based

The Artificial Horizon is based upon the well known principle in Catoptrics—that *the angle of reflection is equal to the angle of incidence:* in other words, if a ray of light strikes any plane reflecting surface at a definite angle, it leaves it at the same angle, thus:—



This fundamental law cannot be too strongly impressed on the mind, as its applicability to everyday matters is continually cropping up. Opticians avail themselves of it in quite a variety of instruments. The sextant is partly based upon it, and it forms a leading feature in the science of lighthouse illumination. Sound waves and heat rays have this property in common, and in mechanics there is the same law precisely. Every billiard player understands it well, as it is applicable to the motion of the balls on the table.

The principle can be illustrated in the simplest possible manner by driving one of the balls against the opposite cushion of the billiard table, and noticing the direction of its motion on approaching the cushion, and again on rebounding from it. If the ball be propelled from the bottom *left*-hand pocket, so that it strikes the exact centre of the top cushion, it will return to the bottom *right*-hand pocket, always supposing that "side" has not been given to it. All schoolboys are practically familiar with it in the common game of hand-ball, although some of the younger ones may possibly never have heard of the above rule relating to it. **Mechanical illustration.**

The Artificial Horizon, in conjunction with the all important sextant, is of service for astronomical observations on shore when the sea horizon is not obtainable. Even if the sea horizon were available, the artificial one possesses many advantages over it. For example, the accuracy of all observations taken with the sea horizon depends, in the first place, upon a correct knowledge of the estimated or measured height of the observer's eye above the sea level, whereas with the Artificial Horizon it is quite immaterial what the height of the eye may be, as it does not enter into the after calculation. **Artificial preferable to Sea horizon.**

Secondly, owing to the uncertainty of the effects of refraction, the apparent position of the sea horizon can never be depended upon. It is found to be sometimes above its normal place, and at others below it. The rule seems to be, that when the sea is *warmer* than the air, the horizon appears *below* its mean place; and when the sea is *colder* than the air, the horizon appears *above* its mean place. The known capriciousness of terrestrial refraction has prevented the formation of a table of values in connection with this subject. **Sea horizon not reliable.** **Irregularity of refraction.**

Celestial refraction also varies much, so that the tabular amount applied to the altitudes of heavenly bodies may not at the time be the actual value. It is important to arrive as nearly as possible at the correct thing, by using auxiliary Tables 32 and 33 of Raper's Epitome, to correct the *mean* refraction given in Table 31. An investigation of the Tables will shew that the refraction is greatest with a high barometer and low thermometer.

Again, if the sea be at all rough, and the observer not much elevated above it, the waves will give a dancing appearance to the horizon, from which the mercurial one is of course exempt. That eminent authority, the late Lieut. Raper, R.N.,* says,— **Sea Horizon saw-edged when rough.**

* Page 188.

"The image of a celestial object reflected from the surface of a fluid at rest, appears as much *below* the true horizontal line as the object itself appears *above* it; the angular distance measured between the object and its image is therefore *double* the altitude. An advantage resulting from this is that in halving the angle shewn by the instrument, *we halve at the same time all the errors of observation.** The reflected image in the fluid is always less bright than the object, but, as it is perfectly formed, and as the surface is truly horizontal, the Artificial Horizon, when it can be employed, is always to be preferred to the sea horizon."

Its use for rating Chronometers

To the navigator, the Artificial Horizon is seldom of other value than to enable him to ascertain the error and rate of his chronometer at ports abroad, where there are no time signals for the purpose. In its use there are many points to be attended to, all of which conduce materially to the desired accuracy of the result.

Size of Trough.

The trough should not be less than 4 inches inside length because the convexity of the mercury at the edges renders that part unfit for reflecting truly. Moreover, the surface of the central portion is necessarily foreshortened to the observer, and becomes more so as the altitude of the object decreases.

The trough should stand sufficiently high inside the roof to admit of the surface of the mercury being on a level with the lower edges of the glasses, otherwise one is needlessly deprived of the full power of the instrument—that is to say, its range for measuring angles is lessened. For the same reason, and also to avoid all possibility of convexity of surface, do not be stingy with the quicksilver. Fill the trough as full as you conveniently can, and do not be content with merely covering the bottom of the dish. The quicksilver is usually contained in an iron bottle, the mouth of which is fitted with a screw plug or stopper. For additional safety, an iron cone (with a fine hole at its apex) screws on over all.

Directions for use.

To fill the trough for observing, proceed as follows :—Carefully wipe clean the glasses of the roof, both inside and out; do this with soft chamois leather, breathing on the glasses to get off specks or stains. Next clean out the trough, and remove all dust from its inside with a hat brush. This is very important, since dust being specifically lighter than mercury, should any be left behind, it will infallibly rise to the surface and mar the observation; then place the trough in its selected position, ready for

* Italics by the author.

filling. Take the iron bottle, remove the cone and plug, and replace the cone, taking care to screw it on pretty tightly, as mercury is very searching. The cone is now intended to do duty as a filter, and to prevent scum from passing into the trough with the quicksilver. To facilitate this, cover the small hole with the finger, and shake the bottle, *holding it upside down, so that the scum may rise to the surface inside.* Then placing it over the trough, and close down (the bottle being still held inverted), remove the finger, and allow the quicksilver to flow. When the trough is sufficiently full, cover the aperture with the finger *before reversing the bottle,* which may then be set down on one side. Scum on Mercury.

It is necessary, when pouring the mercury into the trough, to stop while there yet remains a reasonable quantity in the bottle, otherwise, if it were *all* allowed to run out, the scum would pass with it, and, by clouding the otherwise bright surface of the mercury, oblige you to perform the whole operation over again. To cleanse the mercury when it has become very dirty, run it all out of its own bottle, shake it well up in a soda water bottle with some lump sugar broken small, and then strain it through silk. The action of the sugar is purely mechanical.

Having sufficient mercury in the trough, *immediately* put on the roof to prevent dust getting on its surface, on which it would provokingly float, and impair its brilliancy and reflecting power. It is possible, however, to brush it off by sweeping the surface with the straight edge of a piece of clean blotting paper, cut to the full width of the trough. Dust to be avoided.

To put the mercury back again into the bottle is a more ticklish job, and requires a strong hand to lift the trough, and a steady one to preserve its balance without spilling the contents. To do this, the cone is unscrewed from the neck of the bottle, and inserted in its mouth to act like an ordinary funnel; the mercury is then poured *slowly* into it through a small hole for the purpose, at one corner of the iron trough. To avoid loss, it will be found a good plan to place the bottle in the centre of a wash-hand basin. Careful handling.

It is advisable, also, to have a somewhat larger trough or stand upon which to place the inner one with its roof. This outer stand or stool should have sides about three-quarters of an inch in height, and should be lined at the bottom with thick cloth, into

"The image of a celestial object reflected from the surface of a fluid at rest, appears as much *below* the true horizontal line as the object itself appears *above* it; the angular distance measured between the object and its image is therefore *double* the altitude. An advantage resulting from this is that in halving the angle shewn by the instrument, *we halve at the same time all the errors of observation.** The reflected image in the fluid is always less bright than the object, but, as it is perfectly formed, and as the surface is truly horizontal, the Artificial Horizon, when it can be employed, is always to be preferred to the sea horizon."

Its use for rating Chronometers

To the navigator, the Artificial Horizon is seldom of other value than to enable him to ascertain the error and rate of his chronometer at ports abroad, where there are no time signals for the purpose. In its use there are many points to be attended to, all of which conduce materially to the desired accuracy of the result.

Size of Trough.

The trough should not be less than 4 inches inside length because the convexity of the mercury at the edges renders that part unfit for reflecting truly. Moreover, the surface of the central portion is necessarily foreshortened to the observer, and becomes more so as the altitude of the object decreases.

The trough should stand sufficiently high inside the roof to admit of the surface of the mercury being on a level with the lower edges of the glasses, otherwise one is needlessly deprived of the full power of the instrument—that is to say, its range for measuring angles is lessened. For the same reason, and also to avoid all possibility of convexity of surface, do not be stingy with the quicksilver. Fill the trough as full as you conveniently can, and do not be content with merely covering the bottom of the dish. The quicksilver is usually contained in an iron bottle, the mouth of which is fitted with a screw plug or stopper. For additional safety, an iron cone (with a fine hole at its apex) screws on over all.

Directions for use.

To fill the trough for observing, proceed as follows:—Carefully wipe clean the glasses of the roof, both inside and out; do this with soft chamois leather, breathing on the glasses to get off specks or stains. Next clean out the trough, and remove all dust from its inside with a hat brush. This is very important, since dust being specifically lighter than mercury, should any be left behind, it will infallibly rise to the surface and mar the observation; then place the trough in its selected position, ready for

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It is advisable, also, to have a somewhat larger trough or stand upon which to place the inner one with its roof. This outer stand or stool should have sides about three-quarters of an inch in height, and should be lined at the bottom with thick cloth, into which the metal edges of the roof would sink, and so exclude the external air. Its inside measurement should be fully two inches greater than the outside measurement of the mercury trough, so as to admit of the latter being easily lifted out of it, and also to allow the inner one to be turned in azimuth (as the sun moves onward) without disturbing its level. It should be substantially made of cast iron, of good weight, and fitted with three short legs, something after the manner of a common kitchen pot.

Pure glass for roof, and faces parallel.

The most essential requisite in an Artificial Horizon is, that the glasses forming the roof should be pure and free from flaws or veins, and that the faces of each pane should be ground perfectly parallel. The reason for this is the same as that given in the previous chapter in connection with the index-mirror of the sextant. Should, however, the glasses be imperfect in this respect, the resulting error in the altitude can be eliminated by turning the roof end-for-end in the middle of each set of observations; and to effect this with certainty, one side of the roof should bear a conspicuous mark—a white cross or star painted on it would do very well. When taking pairs of stars on opposite sides of the meridian or zenith, always keep the marked side towards you.*

Elimination of Errors.

Shelter and firm ground.

Intending to take sights with the Artificial Horizon, the first thing is to select a suitable and well sheltered spot, and firm ground should be obtained if possible.

A beginner will be surprised to find how small a movement at a considerable distance will sometimes ruffle the surface of the quicksilver, so as to render observations impossible. On this account the *immediate* vicinity of the shore is generally unsuitable. Though the spot of observation was fully one hundred yards from the water-line, a very moderate swell breaking on the shingly beach in Callao Bay was found to shake the quicksilver of the artificial horizon, when placed in the back yard of the Hospital belonging to the Pacific Steam Navigation Company, so that it was only during "the smooths" that sights could be obtained.

Surface of mercury soon placid after disturbance

For the same reason, avoid the neighbourhood of waterfalls, mills, factories, foundries, and shops of workmen generally. The passing of vehicles on a road may also have a disturbing influence on the mercury. Fortunately this fluid, from its great weight, very quickly comes to rest after being shaken, therefore, so long as the tremor is not actually continuous, one can generally manage

* See pages 553-554.

to secure good observations. Wind is a frequent source of quaking mercury, and care should be taken to have the horizon trough firmly placed, and the roof bedded on something soft, so that the wind cannot get under its lower edge.

Ruffled mercury

A screen of canvas to windward is a good thing as a rule, but on some ground this causes such vibration of the earth as to be worse than the free blast of the wind.*

For "Equal Altitudes," a spot free from disturbance is absolutely necessary, or, from inability to secure observations corresponding in altitude with those taken in the forenoon, the whole day's work may be lost—to say nothing of the annoyance of the thing.

Again, a place open to the public is objectionable, from the number of idle curiosity-mongers who are sure to surround the party, and, without intending it, make themselves very disagreeable by ignorantly getting in the way, &c.

Supposing a spot suitable in all these particulars has been found, there yet remains an important consideration.

If you are going to observe in the afternoon as well as the forenoon, due regard must be had to what the sun's bearing will be at the first named time, so that when wanted in the afternoon it may not be rendered invisible by houses, trees, hills, or other obstructions. This being seen to, get ready for work by filling the trough as before mentioned, and place it nearly in a line with the object to be observed; *but slightly in the direction that the object is moving*, so as to avoid having to slue the trough in azimuth before the completion of the entire set.

How to place trough for observing.

To make delicate observations depending so much upon eye and nerve, *it is necessary to be comfortable in body.* About the easiest position for the observer is, to sit down on the ground at the proper distance from the horizon, and to have the back well supported by a rough box filled with sand or stones, or a chair steadied by someone else sitting on it.

Position of observer.

One cannot be comfortable, however, even on a bed of roses, if half stung to death by mosquitoes; so in countries where these plagues exist, and night observations are required, it will be necessary to give a wide berth to swampy localities, which are sure to be infested by armies of them, especially if the air be still: indeed, for this reason it is preferable to court a breeze instead of shutting it out.

Mosquitoes and Sandflies

* Experiments made at Greenwich Observatory proved that tremors in the mercury were caused by passing trains up to a distance of one mile at least. There is no doubt a great deal depends upon the character of the ground.

Sandflies are yet worse, as *nothing* will get rid of them; even sailors, who are a long-suffering class, and learn to put up with most things, are not proof against their affectionate attentions, and many an otherwise favourable opportunity of getting stars has been spoilt by these diabolical insects.

Should it be intended to observe the sun, turn down *temporarily* the necessary horizon and index-screens; and, being placed so that his image can be seen reflected from the centre of the mercury in the trough, direct the sextant to the sun, and bring it down until it more or less covers the image in the mercury, then quickly turn back the hinged screens—they are no longer needed—in with the telescope, and screw on to its eye-piece a suitable screen, light enough to give a well-defined image of the sun, and yet not too bright to dazzle and fatigue the eye. Beginners are very apt to use too bright suns, and in consequence the effect known as "irradiation," spoils the sharpness of the limbs.* Look to your tangent-screw to see that it is not at the wrong end of its run, which of course would depend upon whether the sun might be rising or falling, otherwise you might find yourself "two blocks" in the middle of a set.† By this time the images will be near the point of separation. Tell your assistant with the chronometer to "look out," and at the *actual* moment of contact of the limbs call out "stop." ‡

Telescope screens preferable to index or horizon screens.

Care as to *which* limb is observed.

In the morning, for *lower* limbs the suns will separate, and for *upper* limbs will close. The contrary is the case in the afternoon, and this is irrespective of the kind of telescope employed, whether *direct* or *inverting* Attention to this rule will prevent any confusion as to which limb was observed.

Observe upper and lower limbs alternately without unclamping the vernier: this neutralizes the effect of irradiation, and gives less work to do in reading off, besides being advantageous in giving practice with both opening and closing suns, and not having it all one way in the forenoon and another in the afternoon.

It is unwise to make the sets too long, as doing so wearies both eye and hand, and the observations suffer accordingly, especially in hot climates, where the necessity of observing in the full glare of the sun makes it a trying operation.

* "Irradiation" is an optical illusion in virtue of which white objects, or those of a very brilliant colour, when seen on a dark ground, look larger than they really are.

† This defect has been obviated by Messrs. Heath & Co. by the use of their *Semper Paratus* endless tangent-screw.

‡ When observing, never "make contact" yourself by moving the tangent-screw, but overlap or open the images, as the case may be, clamp securely, and watch for the exact instant of contact. Use the telescope with greatest magnifying power, as it much facilitates correct contacts.

In "equal altitudes," take care that corresponding observations A.M. and P.M. are made of the same limbs. Ascertain index error immediately before and after sights, *using any of the eye-piece shades which were employed for the altitudes.*

In observing with the Artificial Horizon, it is preferable, for many reasons, to use the screens fitted to the eye-piece of the telescope instead of the hinged ones on the sextant. A couple, and sometimes three, of different degrees of shade are to be found in every decent sextant case, and their advantage over the others will be apparent to the reader who has studied attentively the chapter on the Sextant:—for example, the brilliancy of the sun varies as clouds pass over, and although to meet the contingency you have to change the shades, no inherent error is introduced by doing so, a happy circumstance, and very different to the result obtained by the use of the Index and Horizon Screens, which latter, however, must of necessity be used with the Sea Horizon. **Eye-piece shades.**

Before commencing work, equalize the brightness of the two images by raising or lowering the telescope by the large milled headed screw provided for the purpose. This will bring the axis of the telescope almost in line with the edge of the silvered part of the horizon-glass, which is the best position for observing, and there it must remain all through the performance. No matter, then, what particular depth of shade you may afterwards be compelled to use for the eye-piece, the two images will preserve the same relative tint.* **Correct position for telescope.**

It may assist to give an example of finding the *true* from the *observed* altitude.

♄ 24/7/1875, on shore at Arica, in latitude 18° 28′ 00″ S., and longitude 70° 20′ 25″ W., observed the following *angles* between the *upper* limb of the sun reflected from the index-glass of the sextant, and the *lower* limb as reflected in the artificial horizon. I.E. + 50″.

* In best sextants it is now usual to fit an eye-piece with a revolving disc containing 3 or 4 screens of various intensities, so that a shift from one to the other is only the work of an instant. This arrangement is made to suit each of the telescopes. The disc contains a clear aperture as well as the coloured screens, so that it can be screwed on before commencing to observe, and no time is lost.

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⊙̄	56°	40′	30″
	56	24	20
	56	14	10
	56	04	10
	55	56	30
No. of Obs. ·	5)281	19	40
Mean	56	15	56
Index Error		+	50
	2)56	16	46
	28	08	23
Refraction—Parallax	—	1	38
	28	06	45
Semi-diameter	—	15	47
True Alt. · ⊙	27°	50′	58″

It will be noticed that Dip is not allowed, also that the angles were diminishing, shewing it to have been afternoon, in which case (being upper limb) the observed limbs were *separating*. For an example of stars, *see* page 559.

Observing power of Artificial Horizon.

Recollect that, as the Artificial Horizon gives *double* the actual altitude, you cannot with the ordinary Sextant observe higher altitudes than 60° or 62°; indeed, so high an altitude is not to be recommended, for though the ordinary quintant will measure 135° or thereabouts, the image will not be sharply defined when reflected from the Index-mirror at such a large angle, unless the glass be more than usually good. To save disappointment, it is well to ascertain beforehand what is the lowest altitude your Artificial Horizon will permit you to take;—this is seldom under 18°, which gives you a range in altitude of about 40°. The improved Quintant of Messrs. Hughes & Son will measure angles correctly up to at least 140°.

Requisites to take on shore.

When going on shore for sights, take with you a couple of chairs (unless you think you can borrow them), one for the chronometer, and the other for the time-keeper, and to support your own back as before mentioned. Take also pencil and notebook, chamois leather, a couple of towels to spread on the ground under the instruments, *and, in hot weather, an umbrella to keep the chronometer cool.* You cannot help exposing your sextant *when observing,* but that is no reason why you should do so when *not* observing. Recollect that the metal is amenable to the law of expansion and contraction, and that observations made under opposite conditions of heat and cold cannot be expected to agree. This is one of several reasons why the writer prefers stars. *See* page 553. For night work, dispense with the umbrella, and substitute a couple of bull's-eye lamps—one for the chronometer, and the other for reading off by.

Don't forget the wash-basin or some substitute, unless you have a large reserve stock of quicksilver. Caution the lamp-men neither to flash the light in your eyes nor to throw it anywhere near the Artificial Horizon. A good arrangement is that in which the assistant is seated in the observer's back-supporting chair, with the chronometer immediately facing him on the other, so that the light necessary for taking the time need not interfere with anything else.

For this sort of expedition, select handy men who have some *gumption*. Think over and make all your preparations well in advance, so as to avoid hurry-scurry and confusion when the time for action comes. Compare chronometers before leaving the ship, and again on your return on board.

Artificial Horizons for sea use.

Many Artificial Horizons have been invented for use on board ship in times of fog, or for taking stars at night, when the natural horizon is very ill-defined, but none of them can be considered a success; and unless a man has plenty of money, and can afford to amuse himself with such toys, they are just as well left alone.

THE SEA HORIZON.

Visible horizon.

Every seaman knows that by going aloft in clear weather his range of view is extended, and that on account of the earth's curvature the visible horizon recedes from him the higher he goes. In like manner, by descending towards the surface of the water his range of view is lessened, and the horizon approaches him.

Observations in foggy weather.

Advantage can be taken of this to get observations in foggy weather. By sitting in the bottom of a small boat in smooth water, or on the lowest step of the accommodation ladder, the eye will be about two feet above the sea level, at which height the horizon is little more than a mile and a quarter distant, so that unless the fog is very dense, serviceable observations are quite possible.

The writer, on three different occasions, when at anchor off the River Plate, during fog, has been enabled to ascertain the ship's position in the way described, and after verifying it by the lead, has proceeded up to Monte Video without seeing land. Of course the vessel was only allowed to go at slow speed, and the deep-sea and hand-leads were kept constantly going, as well as the ground-log,—the latter will be treated of by-and-by.

Height of eye above sea level.

Every navigator ought to ascertain, before leaving dock, the height of his eye above the load water-line corresponding to his position on the bridge, upper, and main deck, and consequent distance of the visible horizon as seen from each of these places.

Where to observe from in *clear* weather.

In fine clear weather take your observations from the highest convenient place, say the bridge. The reasons for this are that an error in the dip causes an error of the same amount in the altitude; and the dip changes most rapidly the less the elevation above the sea level. For a height of eye of 10 feet the dip is 3′, and for 40 feet it is only 6′ (*vide* Table 30 of Raper's Epitome).

Raper says:—

"If the altitude be observed above the deck, as in the top for instance, the horizon will appear better defined, and the variations of the dip by the ship's motion will be less sensible; also the difference of temperature of the sea and air appear to affect the place of the visible horizon less as the observer is more elevated. Hence it would appear that altitudes should be taken from aloft when convenient."

Where to observe from in *misty* weather.

In thick or misty weather take your observations from as low a point as possible, and in all cases apply the correction for height of the eye corresponding to what it is known to be at the spot where the observation was taken.

Reference has already been made to the uncertainty in the place of the sea horizon, due to the unequal temperature of the air and water. This displacement of the horizon sometimes occurs to a most serious extent, and unfortunately on board ship there are no means of detecting it *by observations of the sun,* unless, indeed, its altitude should happen to be above 60°, when, with a good Quintant, it can be taken *from opposite sides of the horizon,* by which means, *if the displacement should be equal all round,* the error due to this cause will be eliminated by taking the mean of the observations.

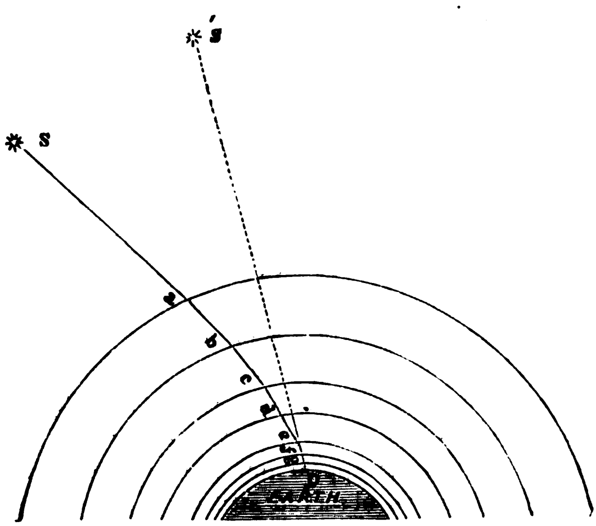
Fore and back observations.

This error in the place of the sea horizon is commonly found on the edge of soundings, and at the mouths of large rivers, and in the latter case is caused by the unequal temperature of the mingling currents of fresh and salt water. It exists in a marked degree in the Gulf Stream and its vicinity.

The writer once found the latitude by an excellent meridian altitude of the sun to be as much as 14′ in error. The time was mid-winter—the day a clear and cloudless one—the sea smooth, and the horizon clean-cut. Five observers at noon agreed within the usual minute or half-minute of arc; nevertheless, on making Long Island (U.S.A.) in less than two hours afterwards, the latitude was found wrong to the amount stated. Many such cases have come under the writer's notice, but this one alone is cited on account of the magnitude of the phenomenon.

As an instance of ignorance of some of the commonest truths in nature, the writer cannot refrain from introducing the following anecdote. Sun below horizon whilst yet visible.

One evening he was pacing the deck with his Chief Officer, and seeing the sun's lower limb touching the horizon, told his companion that at that moment the *whole* of the sun's disc was really below it, although from the effects of refraction it was still visible. This the officer *could not* and *would not* believe. He aptly enough quoted the saying, "Seeing is believing, and feeling is the naked truth." However, he was convinced some few minutes later by a very familiar experiment. Being firmly seated in front of an empty wash-hand basin, so that the brass plug at the bottom was quite invisible, the basin was about half filled with water from a can, when, without moving his head, he at once, to his great astonishment, saw the plug. On letting the water run off, the plug again disappeared. Experiment with basin of water.



The figure represents a portion of the earth surrounded by the atmosphere, the density of which, as shewn by the increasing nearness of the circles, becomes greater as the surface is approached. The ray of light proceeding from the star *S* is successively bent or refracted at the points *a b c d e f g*, and finally comes to the eye of the observer at *O* in the direction *gO*, naturally causing him to imagine the star to be situated in the heavens at *S'*.

It was then explained to him that air, in common with all transparent media, possesses the power of bending rays of light out of their straight course. Explanation of refraction.

A ray of light from a celestial body, entering our atmosphere *obliquely*, is more and more bent down or curved as it approaches the earth, so that when it finally enters the eye, it does so in a direction different to what it had in traversing space.

The denser the air is, the greater the effect produced; consequently, there is more refraction near the surface of the earth than at several miles above it, where the air is thinner.

Water is a much better refracting medium than air. Every sailor is familiar with the bent appearance of an oar-blade in clear smooth water, though he may not know the cause. Literally speaking, then, refraction enables us "to see round corners."

Now it might be supposed that what has just been said about the sun and the horizon, also holds good for the moon. A little knowledge is dangerous, and the *half*-fledged navigator, in his conceit, would be certain to say—"Of course it does!! Why not? Where is the difference?"

From the very much greater nearness of the moon it has a large parallax—quite exceptionally so (*see* page 323)—and this more than counteracts the effect of refraction. Recollect that the true altitude of a body is calculated as if seen from the centre of the earth, with the *rational* horizon as zero. Now the mean horizontal parallax of the moon is 57′, and the mean refraction at the horizon is 34′; the difference is 23′ in favour of parallax, so when the moon's lower limb appears to be touching the horizon it is really 23′ above it. The navigator is left to puzzle over the difference (if any) in these two cases. If *full*-fledged, he will have no difficulty in deciding whether they "run on all fours."

Tug of war.

Parallax the victor.

See, then, how even the evidence of our own eyes, upon which we place such implicit faith, is liable to deceive us. As refraction causes a celestial body to appear higher than it really is, it must always be *subtracted* from the observed altitude. As parallax causes a celestial object to appear lower than it really is, it must always be *added* to the observed altitude. Reference to Table 31 of Raper will shew that refraction is greatest near the horizon, and vanishes when the object is in the zenith.

Diurnal parallax.

This is the case also with diurnal parallax.*

DISAGREEMENT BETWEEN FORENOON AND AFTERNOON SIGHTS.

The question is constantly asked, Can you tell me why it is I can so seldom get my forenoon and afternoon sights to agree? The explanation is simple enough, and as the subject is worthy of

* The qualifier "diurnal" is seldom used except when it is necessary to distinguish between this kind of parallax and the *annual* parallax of the fixed stars. which is due to the earth's orbital motion. (*See* page 320.)

being carefully gone into, an attempt will be made to render it clear.

To simplify matters, the reader will be good enough to suppose himself in a vessel at anchor, in the month of December, some few miles south-eastward of Monte Video, and that his chronometers are exactly correct, and his position known to a nicety by cross bearings of Flores Island and the Cerro.

Elevation or depression of Sea horizon.

Next, let us suppose that, owing to abnormal refraction, the horizon is depressed, say three minutes of arc, and remains in that condition all day.

Let sights be taken at six o'clock in the morning, and again at six in the evening. From the horizon being unduly depressed, these altitudes will be too great by 3 minutes of arc, and when worked out will in each case give too small an hour angle, with the result that the A.M. sights will place the ship 4′ of longitude *eastward* of her true position, and the P.M. sights will place her an equal amount *westward* of her true position, introducing thereby a discrepancy of 8′ of longitude between the morning and afternoon sights—though the sights themselves have been most carefully taken, and the ship has not shifted her position in the least.

To pursue the matter yet further. If the sights were worked with the incorrect latitude obtained from the meridian altitude, still greater error would result. The latitude, from having been worked with an altitude too great by 3′, would itself be in error that amount.

Error due to incorrect latitude.

Now by working the A.M. sights with too northerly a latitude, the resulting longitude is thrown 1½′ still further to the eastward —and in like manner, with the P.M. sights, the resulting longitude is thrown 1½′ still further to the westward.

It follows that an apparently trivial error of 3′ in the position of the sea horizon can *very easily* introduce a discrepancy of 11′ in the longitude as shown by A.M. and P.M. sights. Cases, sufficiently common, could be selected, depending upon latitude, declination and hour angle, where an error of 3′ in the place of the horizon would cause the A.M. and P.M. longitude to differ as much as 15′ or 16′.

Error in course and distance.

From the foregoing we see that discrepancy between forenoon and afternoon sights can arise from the latitude used being slightly incorrect; also from abnormal refraction, from the course and distance in the interval not being altogether what it was supposed to be, and from badly centered and graduated arcs, as well as other imperfections in cheap sextants.

When these causes all happen to conspire together (which must *sometimes* be the case), there may be a very great discrepancy between the A.M. and P.M. observations. Moreover, the navigator is apt to lose sight of the fact that he has carried on his longitude *by dead reckoning* for 6 hours, say from 9 o'clock in the morning till 3 o'clock in the afternoon. He is apt to think he had it exact *at noon*, whereas he only had his *latitude* correct at that time.

Again, to work his sights, he is obliged to use the latitude *by account* worked back from noon; so that, taking all these things into consideration, it cannot be wondered at if there should generally be a discrepancy of results. It would be preferable to take the *mean* of the A.M. and P.M. positions for the true one.

Popular fallacy concerning afternoon sights.

The writer has known officers to look with great suspicion upon afternoon sights, and openly state that they never knew them to come out right, and were not worth taking. The well informed navigator will see that they are as much to be relied upon as similar ones in the forenoon.*

Abnormal refraction in Red Sea and Persian Gulf.

In the Red Sea and Persian Gulf, the horizon is very liable to displacement from the hot winds coming off the scorching deserts, and the refraction in the day time is generally in excess of the tabular value.

The writer has been enabled to practically demonstrate this to the complete satisfaction of his brother officers, during a voyage to Calcutta and back. It was alleged by those on board, who had repeatedly passed certain islands in the Red Sea known as the Zebayir and Hanish groups, that they were not shewn *relatively* in their proper positions on the chart, and to determine the correctness of this statement the writer devoted some considerable time and labour.

Zebayir and Hanish Islands.

The Zebayir Islands lie, roughly speaking, about 70 miles to the northward and westward of the Hanish group, and both of them directly in the track of steamers passing up and down. The distance between them is such, that if one group should be passed about sight time in the morning, the other group will be passed about sight time in the afternoon.†

* To keep up the traditions of the sea, some few men are still in the habit of "making the sun over the foreyard" as soon as "one bell" is struck; which perhaps—according to the amount of "northing" in the grog—has a tendency to render them a little uncertain in their movements later on in the day. But there is absolutely no evidence to shew that steady "Old Sol" thinks he has earned the right to get upon "the loose," or take an afternoon nap, simply because he has done his duty to himself and the world by passing the meridian up to time.

† The distance from Centre Peak Island of the Zebayir group, to High Island off the north end of Jebel Zukur, is 66 miles.

Singular instance of seeming discrepancy in relative longitude.

It was found on the outward passage, when sights were taken in the morning off the Zebayir group, that they were apparently marked too far west on the chart; and when similar observations were made in the afternoon, the Hanish group appeared to be shewn too far east on the chart. This was a serious business, as the relative bearing of the two groups of islands was thereby materially altered. The question, moreover, was one independent of the correctness of the chronometers, as the islands were shewn *relatively* to be out of place some 7 or 8 miles.

After a very careful discussion of all the data in connection with the subject (including observations on previous voyages by other observers), the writer came to the conclusion, that in all probability the altitudes of the sun had been vitiated by excessive refraction. To test this, on the passage home, sights were again taken off the Hanish Islands, *which this time happened to be passed in the morning*, and similar observations made off the Zebayir Islands, *which were passed in the afternoon*, thus reversing the conditions of the outward voyage. The result fully justified the writer's expectations, as the Hanish group were now shewn too far west on the chart, and the Zebayir Islands too far east, while on the outward passage just the opposite had been the case. So that all this bother and uncertainty as to the relative position of two important groups of islands was unmistakably proved to be due in part, if not wholly, to errors of observation, arising from excessive refraction.

In 1895 special attention was paid to Red Sea refraction by Lieutenant W. A. Marshall, U.S.N., of the U.S.S. *Detroit*, and this observer came to the conclusion that the effect of excessive refraction when taking the sun in the Red Sea is a more probable cause of departure from the beaten steamer track than cross currents. With the exception of meridian altitude, the *Detroit* was navigated solely by means of early twilight, dawn, and night stars. In an article signed *Meteor* (William Allingham) in the *Nautical Magazine* for July, 1895, attention was called to this matter, and the opinion expressed that masters will do well to be on their guard against either source of error. In the September number appeared an article by Captain W. H. Hood, a commander of the highest repute, confirming this view. Either excessive refraction, cross currents, or both combined, led to the discovery of the Avocet Rock in the Red Sea by the loss of two steamers upon it. Lieut. Koss and Ensign Thun-Hohenstein, of the Austrian Navy, conducting observations near Pola for finding the variation in the dip of the horizon, observed on a quiet day

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Great caution necessary in navigation.

These things point strongly to the necessity for great caution in the navigation of a ship. Nothing "slapdash" should be allowed in connection with it, nor too much taken for granted Who can tell how many wrecks might be traced to this cause which at the time were ignorantly set down to some extraordinary "jump" of the compasses, or some unlooked for current? Seamen would do well to give this important subject the attention it merits.

CHAPTER VII.

CHARTS.

A few words concerning the nature of Charts, and the difficulty of their construction, will prove both interesting and instructive to the seaman; in any case, it is only right that he should know something about one of the most important of the tools with which he has to work.

Difficulty of Chart construction.

When we attempt to represent any considerable portion of the earth's surface on paper, we are at once met by the formidable difficulty caused by its curved form. A little reflection will convince anyone that it is impossible to make a spherical surface like that of our globe coincide exactly with a flat surface, such as a sheet of paper.

If an orange be cut in two, the inside scraped out of either half, and an attempt then made to flatten the cup-shaped rind on the table, what would happen? It is certain that in so doing the edges would give way and tear up nearly to the centre, showing the impossibility of performing the feat with a non-elastic substance.

It is obvious, therefore, that *no* representation of the earth on a flat sheet of paper, such as a chart, can exhibit all its parts in their true magnitudes and relative positions.

In the construction of charts, it consequently becomes necessary to adopt such a method of laying down the places, which it is intended to depict, as will best fulfil the particular purpose for which they may be required. The various methods adopted for this purpose are called *projections*. Among them may be enumerated the Orthographic, Stereographic, Polyconic, Gnomonic, and Mercator. Of all these, the one commonly used by the seaman is Mercator. It takes its name from the inventor, Gerard Kauffman, commonly known as Mercator (this being the Latin of his surname), who originated the idea about the year 1556; but the *true* principles of the projection—or, more properly speaking, *construction*—were not demonstrated till half a century later, by Mr. Edward Wright, of Caius College, Cambridge.

Chart projections.

For other purposes than those of navigation, a Mercator chart is likely to be extremely misleading; the *meridians* are all drawn as *straight lines* perpendicular to the Equator, and at equal distances from each other. The *parallels of latitude*, also, are represented by *straight lines* parallel to the Equator, and also, like it, at right angles to the meridians. The scale of latitude and distance at either side, instead of being unvarying, increases with the latitude until at the pole it becomes infinite. Hence in making measurements you cannot apply the dividers to any part of the margin at random. Altogether an extraordinary production when compared with the globe as we know it.

The Mercator Chart.

Now, on the *actual* globe, the degrees of latitude are (practically speaking) equal to each other, but the degrees of longitude diminish as they recede from the equator, and converge to a point at the Poles. For example: on the Equator a degree of longitude contains 60 nautical miles, in the latitude of London it contains 37½ miles, in the latitude of 65° North (say at Archangel, in Russia) it contains but 25½ miles, and so goes on lessening in the higher latitudes, until at the North Pole it has no value whatever—which is equal to saying, that *there* longitude has no existence. An observer at the North Pole, let him face round as he may, could only look true South. There is no direction of east or west, by which to convey the idea of longitude, and the sun when visible would always be on the meridian.

Varying lengths of degrees of longitude.

Since in the Mercator construction the meridians, as already stated, are equidistant in every part, and the degrees of longitude are everywhere made equal to their dimensions on the Equator; it becomes necessary, in order to preserve a due proportion between them and the degrees of latitude, to increase the length of the latter in a corresponding ratio. From the true proportions being preserved throughout between the meridians and the parallels, the *shapes* of the objects delineated on the chart are in every part correct. But as the *lengths* of the degrees both of latitude and longitude, at a distance from the Equator, are enormously ex-

Earth's surface distorted in the Mercator projection.

aggerated, the *sizes* of the objects in those parts of the chart are increased accordingly: so that the whole map, if it comprises many degrees of latitude on one side of the Equator, gives a most inaccurate notion of the *relative magnitudes* of its northern and southern parts.

Distrust appearances.

For instance, looking at the Admiralty General Chart of the North Atlantic, No. 2059, there will be found in Ungava Bay, on the north coast of Labrador, an island named Akpatok; and to the southward of Cuba, in the Caribbean Sea, will be found the well-known island of Jamaica. Anyone looking at the chart, and unacquainted with the facts detailed above, would undoubtedly think these two islands were exactly of the same length, and would be confirmed in this impression by actual measurement with dividers. But, following out the rule governing measurements on a Mercator Chart, whereby it becomes necessary to measure the dimensions of each object *in its own parallel of latitude*, it will astonish the uninitiated to find that the island of Akpatok is 65 miles in length, while that of Jamaica is 130 miles, or exactly double. This example will put the wary navigator on his guard not to trust to appearances without first thoroughly understanding the *principles* which govern them.

This defect in the Mercator Chart does not in any way detract from its utility for nautical purposes.

Utility of Mercator's Chart for nautical purposes.

Its great advantage to the sailor consists in the fact that—1st, the ship's course between any two places, however remote, is *represented by a straight line*; 2nd, *this line makes the same angle with each meridian*. Therefore, to find the true course (or rhumb line) on the chart from any one point to any other, it is only necessary to connect them by a straight pencil line, and measure its angle with any one of the meridians which it crosses. This may be accomplished with a common horn protractor; or, as is more usually done, by transferring with a pair of parallel rulers the direction of the aforesaid line to the nearest *true* compass diagram, and so at once read off the course or bearing in points and quarter points. If this course can be carefully preserved, the port bound to will in due time be reached.

In the chapter on Great Circle Sailing it will be demonstrated that, in following up this subject, there are other important matters to be taken into consideration by the man who wishes to subscribe himself, "Yours truly, A Master Mariner."

This construction of Mercator is not exact in very high latitudes, because cross-bearings of several distant visible objects, which are in fact the same as Great Circle courses, are projected on the chart as straight lines, when they are in reality curves; therefore their intersections will not agree; or, three objects seen in range will not, when projected in their true places on the chart, lie in a straight line. For this reason a Mercator Chart would not be suitable for Polar navigation. Indeed they could not be drawn by the draughtsman, since, according to the principles of the construction, the poles are at an infinite distance, and could not be shewn on paper. For unusually high latitudes the Gnomonic projection is employed. It assumes the eye to be at the centre of the earth, and any straight line drawn on such a chart represents the arc of a Great Circle. Its use is limited to small circular areas such as the Polar regions. Near the boundaries there is a certain amount of distortion, but round about the centre of the chart it may be said that nature is correctly represented.

Mercator's Chart inexact in very high latitudes.

From the foregoing it will be apparent that a Mercator Chart gives a very incorrect representation of the earth's surface; but, of all the known projections, it is the one best adapted to the wants of the seaman, and has therefore, with the exception just given, been universally adopted for his guidance.

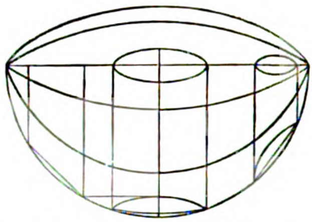
To treat at any length of the other projections of the sphere—more especially the Gnomonic—would be to encroach on the province of the surveyor and of the map-maker, which is not the intention of this work.* For harbour plans the earth is considered a plane, and no account whatever is taken of its curvature, which would be quite inappreciable within the confined limits of such a survey.

Harbour Plans.

In the *Orthographic* Projection the eye is assumed to be at an infinite distance from the object, so that all lines drawn to it may be regarded as parallel. If, then, from every point on the surface of the sphere, lines be drawn perpendicular to the plane of a circle passing through its centre, their points of intersection with this plane will be an *Orthographic* projection. It is obvious that *equal* parts upon the surface of the sphere are seldom represented *on the plane* by parts either *equal* or *similar*, since they diminish progressively from the centre to the circumference. The central portions of the map are shewn nearly in their true proportions, but the more distant parts are greatly distorted in form and diminished in size. This is exactly the reverse to what happens in the *Stereographic* Projection, where the central parts are unduly contracted as compared with the outlying ones. The *Orthographic*—except for certain astronomical purposes—is seldom used.

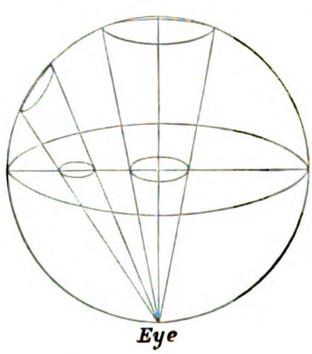
* The Gnomonic is very clearly described in the late Admiral Wharton's *Hydrographical Surveying;* and also in *The Development of Great Circle Sailing*, by Mr. G. H. Littlehales, issued by the United States Hydrographic Office, Washington, D.C.

ORTHOGRAPHIC PROJECTION.



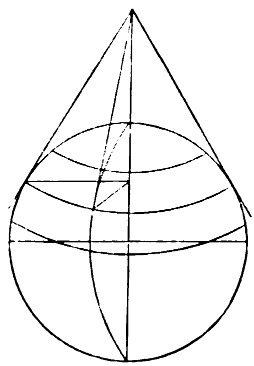
In the *Stereographic* Projection the eye is supposed to be placed on the surface of the globe, and to be vertically over the centre of the plane of projection, or everywhere 90° distant from it. If the globe were transparent the eye would then see the inside or concave surface of the *opposite* hemisphere. Supposing straight lines were drawn from the eye to each point of this hemisphere, their intersection with the plane of projection would be its *Stereographic* projection. Its most interesting property is that, by means of a scale graduated according to the central meridian of the map, the direct distance from its centre to any other place can be measured: also, by marking the points of the compass round the circumference, the bearing of the place will be seen. From this it is evident, that whatever place be taken as a centre, the *Stereographic* projection on the plane of its horizon will exhibit all its environs in their proper relations to it. On the whole, this is the best simple projection for *mapping* purposes.

STEREOGRAPHIC PROJECTION.



The *Polyconic* Projection was much in favour with the United States Coast Survey, and special Tables were framed to facilitate its application. These were republished by the Bureau of Navigation in 1855. They are based on a development of the earth's surface, which assumes each parallel to be represented on a plane by the development of a cone having the parallel for its base, and its vertex in the point where a tangent to the parallel intersects the earth's axis. The degrees on this parallel preserve their true length, and the general distortion of figure is less than in any other mode of representing a given portion of the earth's surface. There are various modifications of it; here is one.

CONICAL PROJECTION.



In providing his ship with charts, it will be a matter for the navigator's consideration as to whether he should procure Admiralty or Blue-backed Charts. On this point there is considerable diversity of opinion, though it would appear of late years as if the former were gaining favour, and becoming more popular with shipmasters. **Admiralty Charts versus Blue-backs.**

It is the opinion of the writer that none can compare with those issued by the Hydrographic Office of our own Admiralty, that of the French Government, and of the United States of America.* In the first place, they are wonderfully cheap, which is ofttimes a consideration; in the next place, they are *official documents*, emanating from the highest authorities; and it would probably be safer to get your ship ashore through any omission or error in a Government Chart, than through a similar one in a "blue-back chart," especially as it will sometimes happen that the first-named possess the very latest information, which the others may not.

Some recent decisions at "*Board of Trade inquiries into the losses of ships*," go to show that the authorities display a preference for the Admiralty Chart. No doubt the proprietors of the "Blue-backs" do all in their power to get the "latest corrections," and keep their works up to the mark; but it is difficult to see how they can successfully compete with a Government office, possessing a hundred times their resources. Though no doubt they do their best, they can only in many cases get their information second-hand. **Admiralty Charts preferred by Courts of Inquiry.**

* The engraving of the French and American Charts is scarcely bold enough for ship's use.

By way of affording a standard of comparison, it may be stated that the Hydrographic Office, in London, issues and keeps up to date over 3,800 charts, against about 300 issued by the largest of the private publishers. These figures speak for themselves.

To the mind of the writer, the Admiralty publications offer superior advantages. They are almost invariably on an appropriate scale; their delineation is remarkable for its clearness; a glance tells which is land and which is water; *correct magnetic* compass diagrams (except on General Ocean Charts) are inserted at convenient intervals, and the charts themselves are never cumbersome in point of size. They leave no wants unsupplied by showing too little, nor do they confuse by showing too much. The art of the draughtsman and engraver is exhibited in all the details, and not the least advantage is the uniformity of system which characterizes each one.* In fact, a home coast sheet, as we know it in these days of exact surveying, with every detail of land, with every rock and shoal, with every depth of water and

Attempts to Boycott "Wrinkles."

* A reviewer of the 1st Ed. of "Wrinkles," in a well-known periodical, for which the writer of these pages has not only much veneration, but likewise a loving regard, coolly suggested that the paragraphs having reference to "Blue-backs" should be re-written in a more favourable strain, as in his (the reviewer's) opinion, they bear unjustly upon the publications in question. The writer regrets that his convictions will not allow him to comply with this modest suggestion, and that in studying the sailor's interests he is obliged to run counter to those of other people. In this matter of charts—so long as present conditions exist—the writer's colours are "nailed to the mast," and whilst freely admitting the meritorious character of the work done by private firms long before the machinery of the Hydrographic Department of the Admiralty had attained its present excellence, he thinks the day of "Blue-backs" has departed, and that it is only a question of time as to when they will be completely snuffed out by the overwhelming resources at command of the Government, to say nothing of the boundless advantages afforded by an *unlimited exchequer*. It is not so very long since the Government, for the good of the Commonwealth, took over the telegraph lines from the private companies, and similarly for a few thousands they might buy up the chart publishers, who, as firms of long-standing reputation, must groan under the hardship of seeing their means of livelihood slowly but surely undermined by an all-powerful department, against which it is impossible, in the nature of things, they can hope to compete on anything like equal terms. Certain Government departments are very absorbent in their nature. Like Victor Hugo's devil-fish, they stretch forth their long tentacles, and without compunction absorb everything they can assimilate that comes within reach. The Blue-backers are being absorbed. Hard lines!! Since in these pages the author has assumed the *rôle* of guide, he is constrained to express an honest opinion in all that concerns his brother seamen, notwithstanding that doing so means a pecuniary loss to himself, inasmuch as certain "Cheap Johns" in the "shoptician" way of business, who recognize their own portraits here and there throughout the book, have not only declined to sell "Wrinkles" themselves, but have endeavoured to prevent others doing so. They might just as well try to stop Niagara with a corn broom. The innate love of fairplay—so strong a characteristic of Britons—will capsize any attempt to "Boycott" the book, and indeed the call for yet another edition in so short a time shews that the gentry in question may as well accept defeat and throw up the sponge, *bon gré mal gré*.

nature of bottom, accurately marked at regular and small distances, is a credit to human ingenuity and a testimony of man's intelligence. On the large scale Harbour plans, the practice is invariably followed of giving the exact latitude and longitude of some well defined spot, and from this any other position on the plan can be easily determined by means of two scales—one for latitude and distance, the other for longitude. This comes in handy for rating chronometers by sun or stars, and for other purposes. The Admiralty charts and plans also give the meridian upon which the longitude depends; consequently, should that meridian at any time be better determined, the correction can be applied without further trouble. The longitude scale of Harbour plans is made as follows:—Assume the latitude to be 50°, and the scale of the plan to be 4 inches = 1′ of latitude or distance. To the common log of 4 add the cosine of 50°; the nat. number of the resulting log will be the number of inches = 1′ of longitude, namely, 2·571. You can check this by the Traverse Tables (Raper, page 511). Against 400 will be found 257·1,—shift the decimal two places to the left and you have it. Knowing this, any fellow can make a scale for himself if necessary. **Harbour Plans** **Scale of distance.**

The value of a chart must manifestly depend upon the accuracy of the survey on which it is based, and this becomes more important the larger is the scale of the chart. To estimate this, the date of the survey, which is always given in the title of Admiralty sheets, is a good guide. Besides the changes that, in waters where sand or mud prevails, may have taken place since the date of the survey, the earlier surveys were mostly made under circumstances that precluded great accuracy of detail, and until a plan founded on such a survey is tested, it should be regarded with caution.

It may indeed be said that, except in well-frequented harbours and their approaches, no surveys yet made have been so minute in their examination of the bottom *as to make it certain* that all dangers have been found. The fulness or scantiness of the soundings is another method of estimating the completeness of a chart. When the soundings are sparse, or unevenly distributed, it may be taken for granted that the survey was not in great detail. Blank spaces among soundings mean that no soundings have been obtained in those spots. When the soundings round about are deep, it may with fairness be assumed that in the blanks the water is also deep; but when they are shallow, or it can be seen from the rest of the chart that reefs or banks are present, such blanks should be regarded with suspicion. This is especially **Chart indications.**

the case in coral regions and off rocky coasts, and it should be remembered that, in waters where rocks abound, it is always *possible* that a survey, however complete and detailed, may have failed to find every small patch, as with the Avocet Rock in the Red Sea.

When dangers shew themselves.

A wide berth should therefore be given to every rocky shore or patch, *especially in smooth water*. With a good high swell, dangerous places are sure to shew themselves, and a hand aloft at such times may save the ship. In dealing with charts, the following rule should be followed:—

Instead of considering a coast to be clear unless it is shewn to be foul, the contrary should be assumed.

Difference in surveys.

Except in plans of harbours that have been surveyed in detail, the five-fathom line on most Admiralty charts is to be considered as a caution or 'danger signal' against unnecessarily approaching the shore or bank within that line, on account of the possibility of the existence of undiscovered inequalities of the bottom, which nothing but an *elaborate detailed survey* could reveal. In general surveys of coasts, or of little frequented anchorages, the necessities of navigation do not demand the great expenditure of time required for such a detailed survey. It is not contemplated that ships will approach the shore in such localities without taking special precautions.

Contour lines.

The ten-fathom line is, on rocky shores, another warning, especially for vessels of deep draught. Charts where bottom contour or fathom-lines are not marked must be especially regarded with caution, as it generally means that soundings were too scanty, and the bottom too uneven, to enable them to be drawn with accuracy.

Isolated soundings, shoaler than surrounding depths, should always be avoided—especially if ringed round—as there is no knowing how closely the spot may have been examined, and mountain tops are occasionally fond of just stopping short of the surface, as if they were lying in wait for the unwary.

Choice of objects for bearings.

In approaching land or dangerous banks, regard must always be had to the *scale* of the chart used. A small error in laying down a position means only yards on a big scale chart, whereas on a small scale the same amount of displacement means large fractions of a mile. For the same reason, near objects should be used for bearings in preference to objects further off, although the latter may be more prominent, as a small error in bearing, or in laying it down on the chart, has a greater effect in misplacing the position in proportion to the length of the line to be drawn.

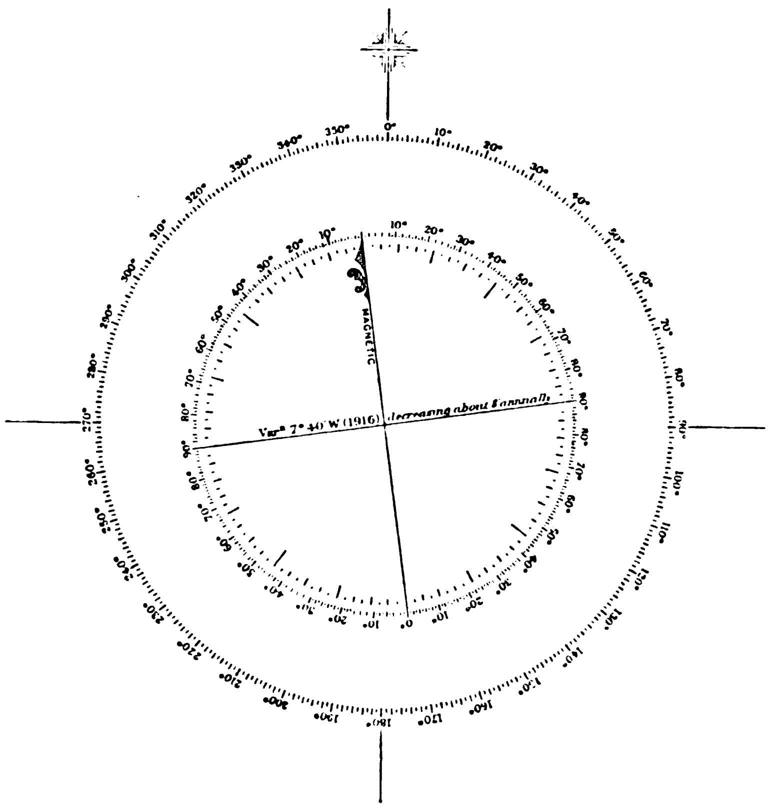
To be properly fitted out, a ship should be provided not only with large-scale coast sheets, but with plans of harbours intended to be visited. It sometimes happens from press of work that only the copper-plate of the larger scale chart of a particular locality can at once receive any extensive rearrangement of coast-line or soundings. This is an additional reason, besides the obvious one of its possessing fuller detail, why the largest scale available should always be used for navigating. Chart corrections.

The printing of charts is responsible for a source of inaccuracy little known to sailors. The paper used in the process has to be damped, or the impression would be too faint. On drying, distortion takes place, from the inequalities in the paper and the amount and irregularity of the original damping. It must not therefore be expected that very accurate series of angles to different points will always exactly agree when carefully plotted upon the chart, especially if the lines to objects be long. The larger the sheet, the greater the amount of this distortion; but it is never so great as to affect navigation. Distortion of paper.

The chart *maker* takes care not to damp his paper, but it is one of his troubles that the atmosphere insists upon doing it for him. For really accurate plotting of the large triangles of a survey, the sides should all be calculated in advance, and the chief points laid down at one sitting, whilst the hygrometric conditions are the same. Our variable climate makes this a rather difficult matter in practice.

It is now pretty generally recognised that on ocean charts the compass roses should only indicate the *true* points. All other sheets should shew the *correct magnetic* points, half points, and quarter points. These diagrams cannot be too plain and free from ornamental devices. Where possible, their diameter should be 3 inches, but never less than 2½. The latest Admiralty pattern of compass rose is as recent as 1st January, 1912, on and after which date TRUE bearings will be introduced in all Admiralty publications as soon as practicable. Outside of, and clearly separated from, the *magnetic* compass and circle, which is graduated in points and degrees from 0° to 90° in each quadrant, the Admiralty now places a *true* compass graduated from 0° (True North) to 360°, measured clock-wise. The bearings of leading and clearing marks on Admiralty Charts will be given both True and Magnetic ; and a note to that effect will be placed on the title of each chart. Thus—298° (N. 54° W. Mag.) is self explanatory. Similarly, on the bearing of, say, Compass diagrams.

S. 40° W. true, with variation 12° E., this information will be indicated as 220° (S. 28° W. Mag.). The modern navigator will, in this way, be able to disperse with N., S., E., W., etc., when setting a course; and simply confine himself to the number of degrees from N., measured clock-wise.



Magnetic degree circle.

The objection to a *magnetic* degree circle is that its accuracy is more apparent than real. In parts of the world where the variation changes rapidly, it is all "moonshine." Round our own coasts, where the change is 1° in seven years, such a circle is practically useless. It looks nice, and that is all.

It thus becomes a question whether it would not be better to do away with the *magnetic* degree circle altogether. If degrees are wanted, let them be *true*, and, to enable them to be read easily, the diameter of the circle should be four inches. Then, with an inner *magnetic* compass rose of three inches—quite big enough—

there would be an intervening blank of half an inch all round, which would conduce to clearness of expression, and prevent possibility of confusion.

On the other hand, should the argument in favour of the horn or other protractor be accepted, we come back to the simple *magnetic* compass-rose shewing points and quarter-points without circles of any kind. No doubt each kind will have its advocates, but the writer believes in simplicity.

The *magnetic* bearing or course may be wanted in a hurry, and if so, a compass-rose divided to quarter-points cannot be beaten as things go at present. The determination of the *true* course is always performed with deliberation, and in the chart-room, where the graduated rolling parallel ruler or other form of protractor is at hand.

Compass diagrams should be clear and simple.

In any case, the present Admiralty diagram is a vast improvement on the system which used to be in vogue with "Blue-back" charts when the writer was a youngster. The manner then in which compasses, true and magnetic, got mixed up and sprawled all over the shop was something wondrous to behold. The arrangement could not have been better calculated to give rise to mistakes at critical times—indeed, the writer has known it to do so. The vessel referred to got on the rocks a few miles to the eastward of Queenstown, but luckily bumped off again without springing a leak, though her bottom was dented in like an old tin pot. The skipper was on the bridge, using a chart with a compass compared with which a spider's web was simplicity itself. As might be expected, he got confused with the jumble of lines, and ashore she went. The writer was on the after-wheelhouse at the time, and the first bang sent him flying down on top of a pompous-looking passenger, who, no doubt, would remember the 'regrettable incident' for quite a long time afterwards.

Elaborate diagrams confuse

Coming to the subject of "Blue-back" charts, a great drawback is the absence, in many instances, of the heights of mountain ranges, peaks, hills, islands, and lighthouses. These are all of great assistance in navigation, and no chart is complete without them. Lighthouse heights, when not on the chart, can, it is true, be got from the lighthouse-book, but it is more convenient to have them on the chart.

Admiralty charts can be backed with "brown holland," which, so far as the material is concerned, makes them last almost for ever; but it increases the expense, and, seeing that some sheets are continually having alterations made in them, according as the

Holland backing unnecessary except in special cases.

banks and channels shift about, it is not advisable to resort to backing.* It gives them a dangerously permanent character.

Except, perhaps, for the smaller class of vessels, where the Captain buys his own charts, the unwieldy "blue-back" has had its day, and it is only a question of "How long?" until it is superseded by the cheaper and handier productions of the Admiralty. As a result of trying to make them suit all purposes, the scale of the blue charts is, in general, *too large for ocean navigation, and not large enough for coast work.*

Scale of Blue-Backs.

In case an Admiralty sheet should be destroyed by the capsizing of an ink bottle, the spilling of lamp oil, or any of the accidents which *do* happen, it is merely a loss of from one to five shillings; whereas, when its rival comes to grief, it cannot be replaced under from ten to fifteen shillings. Moreover, the extra cost of the latter offers temptation to keep it in use till completely out of date, and so marked and smudged as to be in many places illegible—a circumstance likely to lead to disaster, if indeed it has not already done so. The Board of Trade has lately become very particular on this point, and one of the official notices directs the attention of shipowners, and their servants and agents, to the necessity of seeing that the charts taken or sent on board their ships *are corrected down to the time of sailing.* A court of inquiry into the loss of the British sailing ship *G. W. Wolff* commented severely upon the fact that the navigating charts were not accessible to the officers, and expressed an opinion "that masters of sea-going ships should be compelled by law to have the chart by which a vessel is being navigated accessible at all times for reference by the navigating officers." This does not stand alone.

Board of Trade Notice.

With the Admiralty chart the sailor can see at a glance if he has the latest information. The year and the month of the various corrections are engraved at the foot; should the correction be large, the notation is made against the imprint; if small, it is given in the left-hand bottom corner; thus an Admiralty chart tells its own history. Perhaps some day the private publishers may see the advantage of adopting the same system.

Charts should invariably be kept flat, ready for the rulers to slide over them, instead of being rolled up, and folding them should be avoided if possible. Rolled paper is an abomination at all times—

"It will and it won't,
It can't and it don't;"

* In the case of Magnetic Charts of the World, which are only published about once in ten years, of course "backing" is advisable, and here is the way to do it:—Wring the brown holland well out in cold water, and then tack it round the edge of a drawing-board or small table: rub the paste on to the holland with a hard brush: damp the *back* of the chart with a sponge until the *face* looks dull, then roll it evenly up on a clean, smoothly-turned wooden roller: place this on the near side of the holland, and unroll carefully: leave it until all is quite dry. The most recent is for 1912, published by the Admiralty.

The paste should be made with best flour, mixed very thick with cold water. To a and if you lose your temper, you tear it, and so make bad worse. Every vessel, therefore, should be provided with shallow chart drawers, say 3 ft. 9 in. long, by 2 ft. wide and 4 in. deep. The sheets can then be numbered and classified, and so are ready for use at a moment's notice.

Chart drawers preferable to chart racks.

When the writer some years ago was in the habit of navigating Magellan Strait and the many hundred miles of intricate channels leading from it to the Gulf of Peñas, and thence to Chiloé, it was necessary to keep the charts and plans on the bridge for constant reference; but seeing that the climate of that region is probably about the most rainy and tempestuous in the world, means had to be devised to protect the charts from the weather, or they would speedily have become so much pulp. This was accomplished as follows.

Wood backing for charts.

First of all, the sheets of the various channels were cut up into convenient lengths, and the carpenter was brought into requisition to make teak-wood backings for them of well-seasoned half-inch stuff, dressed smooth. The backing was made an inch longer and broader than the chart or plan it was intended to receive.

Next, some 'size' was made by filling a breakfast cup with isinglass, and pouring on it as much boiling water as the cup would hold. After the 'size' had cooled, and was just beginning to thicken, *both* sides of the chart got several good coats, rubbed in with a soft brush as fast as the paper would take it. When the 'size' was well absorbed and had partially dried, the *back* was treated with flour paste free from lumps, and laid on smoothly, after which the chart was put down on the teak-wood: this had to be done very carefully to avoid creases.

To make the paper lie evenly and to prevent air-bubbles from remaining underneath, a wooden roller was run from top to bottom and back again. This rolling process must not be overdone, or it will cause distortion; and it is as well to place the roller on the middle of the sheet at starting, and roll from you, and then back again the whole way; this with a turn or two sideways ought to be sufficient.

Canada balsam.

When the chart had thoroughly dried on the board, both it and the teak-wood received three flowing coats of white varnish, made by mixing Canada balsam with twice its weight of best oil of turpentine. Each coat was laid on with a broad, flat, camel-hair

dessert-spoonful of brown sugar add five drops of oil of lavender, and five drops of corrosive sublimate; mix this well up with the flour and water, and then add perfectly boiling water to the thickness of custard.

brush, and allowed to get perfectly hard before the next was applied.

Sizing and varnishing.

When treated in this manner the charts were completely weather-proof, and equal to any amount of rough usage. Should the 'size' in the cup get hard like jelly, a few minutes on the stove will bring it back to a proper consistency.

Bridge Chart-table.

This was the writer's dodge some fifteen to twenty years ago, and in the interval steamers have not got slower nor navigation less exacting. These facts, coupled with a perusal of "Wrinkles," led Mr. S. Manning, of Surbiton, Surrey, to devise a chart table for bridge use which would do away with the need of the drastic measures just detailed. The invention consists of a frame, in which is bedded a specially prepared sheet of glass, so treated that though it will readily take pen or pencil marks, is of such transparency that the chart detail can be seen through it. Courses or bearings can therefore be set out on the surface, or the Station Pointer applied, without injury to the chart underneath, *no matter what the weather may be.* The arrangement is well spoken of by practical men.

How utilised at night.

The great need for a contrivance of this kind, and its value, will be thoroughly appreciated by anyone who has had to consult charts in wet or windy weather. The valuable time that is usually lost in running below and having to remove waterproofs before the chart can be approached, will now be spent on the bridge, where the whole situation is spread out before the anxious navigator, and his guide is at hand. The wetter the weather, the more transparent the glass. By having the bottom of the table of glass also, and four or five incandescent electric lamps properly boxed in below it, the table would be available for night work. When not actually in use it could be covered with a cloth. This is a suggestion of the writer's, and does not form part of Mr. Manning's invention. Should he read it here, he will no doubt utilise it. Do so by all means, Mr. Manning.

Many vessels have been lost owing to their being economically (?) navigated near land by small scale charts, which cannot possibly shew coast dangers.

Wharton,* in alluding to the increasing necessity for large scale charts constructed from detailed surveys, says:—"A steamer works against time; her paying capabilities largely depend on her getting quickly from port to port, and captains will take

* *Hydrographical Surveying*, page 52.

every practicable short cut that offers, and shave round capes and corners in a manner to be deprecated, but which will continue as long as celerity is an object. A channel which a sailing vessel will work through in perfect safety, from the obvious necessity of keeping a certain distance off shore, for fear of failing wind, missing stays, &c., will be the scene of the wreck of many a steamer, from the inveterate love of shortening distances, and going too near to dangerous coasts only imperfectly surveyed. Better charts will not cure navigators of this propensity, but will save many disasters by revealing unknown dangers near the land." **Cutting off corners in Navigation.**

The late Admiral Wharton might have added that this "short cut navigation" is not only due to fierce competition in trade, but unfortunately to an unwise rivalry among seamen themselves, and an utter disregard on their part of the maxim "Let every man steer by his own compass." Because Brown and Jones do certain things which look very like putting their heads in the fire, Robinson—even against his better judgment—thinks he must do the same, and so the thing goes on till the weakest comes to the wall.

Charts and Sailing Directories are as much part of the ship's equipment as the *Compass* or the *Lead*, and should be provided by the owner. When the captain has no longer to pay for them, he will keep a better stock, and not take his ship all over the world by one or two general charts, to the manifest risk of life and property. Mr. Henry MacIver, a Liverpool shipowner, so long ago as 1885, in a letter to the *Times*, pointed out *inter alia* that "reliable charts and chronometers are more conducive to safe navigation than lifebuoys, foghorns, and the other paraphernalia to which Board of Trade surveyors devote so much attention, and owners should be compelled by law to furnish their vessels with all that may be required." Many shipowners, he said, "required their masters to provide both charts and chronometers, the latter have to economise by reason of small salaries, and accidents frequently happen in consequence." **Owners should provide Charts**

In Appendix (P) will be found the signs and abbreviations adopted in the Admiralty charts.

One more "wrinkle," though a simple one, for which the writer is indebted to Captain Matt. B. Walker, of South Shields. Use *hexagonal* pencils; they won't roll off the table like round ones, and are just as cheap. Common sense.* **Pencils.**

* *Triangular* pencils are still better calculated to remain where they are told.

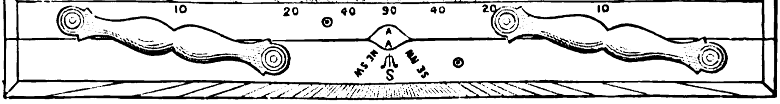
CHAPTER VIII.

THE PARALLEL RULER.

This, in its commonest form, is an instrument so very familiar to the seaman, and withal so simple in itself, that it may seem rather absurd to refer to it; nevertheless, there is *something* to be said even about the parallel ruler, and it *may* so happen that that *something*—or a portion of it—may be new to the reader.

The ordinary black ruler, with brass joints, is usually employed to *transfer the direction* of a bearing or course to the nearest compass diagram on the chart, whereby to ascertain its name and value. Now, in ocean charts, where compass diagrams are very properly few and far between, a great deal of slipping and sliding, and trying back, as well as "smudging" of the chart, may be saved, and much greater accuracy ensured, by the use of a kindred instrument, known as "*Captain Field's Improved Parallel Ruler.*"

Field's Improved Parallel Ruler.



Apparently, at first sight, it only differs from the other in being made of boxwood instead of ebony; but a closer inspection reveals that one ot its edges is divided into degrees, similar to the 6-inch ivory protractor found in most small cases of mathematical instruments; the opposite edge is also divided, but in points, half-points, and quarter-points; these latter, however, are never likely to be used, as the degree marked side of the ruler is preferable.

How to use it.

The advantage derived from this instrument is, that by laying it down on the course you wish to determine, *so that its centre mark shall be on a meridian line,* you at once read off the true course on the divided edge, *where it is cut by the aforesaid meridian line.*

Few things can be neater or handier in practice, and it gives the course in degrees (and by estimation, to parts of a degree), with an accuracy but little short of that obtained by actual computation. The ruler is to be had in three sizes; but the two smaller ones, from the minuteness of the angular divisions, are not to be recommended. The 24-inch ruler will be found very convenient, and the marking clear and well defined. After it has been in use a little time, get it cleaned and *French-polished*.

Size of Ruler.

This is one of the many things which have been improved upon. The improvement consists in discarding the points on the lower edge, and substituting the centre-mark of the degree divisions. By this means the short radius is just double what it was before, and the divisions at the middle of the ruler are in consequence much plainer. You must take care to keep this new form from warping. When shut, the two parts must fit as closely together as they did when being graduated.

Improvement on Field's improvement.

Even better than the above is the graduated *rolling* parallel ruler. On shore this has been in use for ever so many years, but it is only of late that it has found its way on board ship. Of all the means for determining courses or laying off bearings this is about the quickest. Since only the rollers touch, it has the further advantage of not soiling the chart so much as the jointed ruler, which is in contact over its whole surface. To work truly, the rollers must be *exactly* of the same diameter; this is easily tested before purchase. Carefully set the further edge of the ruler to the bottom marginal line of a chart; run the ruler nearly up to the top, and draw a fine pencil line along *both* edges. (In passing, let it be noted that it requires a practised hand to rule a *perfectly* straight line; the pencil must be held at exactly the same inclination throughout.) Now shift the ruler end for end, set the further edge to the bottom line as carefully as before, and roll up within an eighth of an inch or so of the top pencil line. Draw two more pencil lines along top and bottom edges respectively, and the thing is done. The eye will decide in a moment if the upper pair of lines are parallel, as they should be; if so, then the rollers are equal. Next examine the lower pair of lines; if parallel, then the two edges of the ruler are parallel, as they should be. A good instrument-maker will see to these matters for the sake of his own reputation; nevertheless, it is satisfactory to try for one's self. Of course the chart or paper must be laid on a flat surface. The mahogany top of a chart-table, when the wood is well seasoned and the ends strongly

Graduated Rolling parallel ruler

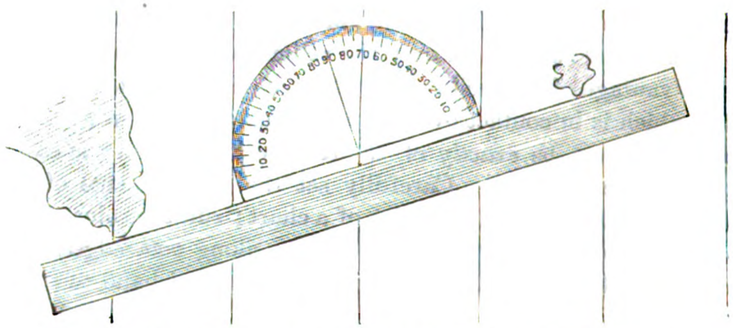
clamped, should remain as flat as the day it left the joiner's bench. The graduated rolling parallel ruler is, at present, a trifle more expensive than its brethren.

The Horn Protractor.

The ordinary parallel ruler, or indeed a straight-edge of any kind, when used in conjunction with a common semi-circular horn protractor, will give satisfaction to the less fastidious. If you have not a horn protractor, it can be procured for a shilling or two at any optician's. Do not get one with a less radius than 3½ or 4 inches, which is a good serviceable size.

To use it, proceed as follows:—

Having the chart on the table, with its north side from you as usual, lay the straight-edge over the course you wish to steer or determine, and place close against it (edge to edge) the horn protractor, sliding the latter along (its straight side being always in contact with the ruler) *till its centre mark comes fair over any meridian line on the chart;* the exact true course in degrees and half degrees will be found at the circumference, where the latter is cut by the same meridian line, thus:—



In this particular case it is N. 70° E. or S. 70° W. (true).

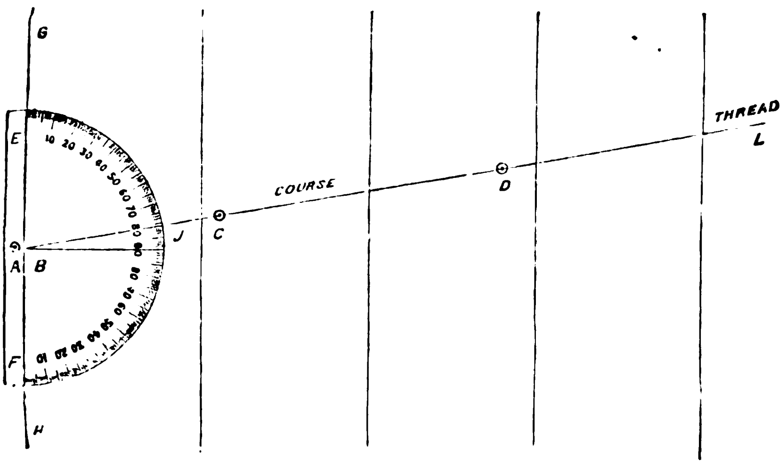
Almost every one going to sea *abaft* the mast has a gunter's scale, which would answer first-rate with the horn protractor in the manner just described; but if there should not be one, and the parallel ruler be broken or lost, any lath or piece of wood, dressed straight with the carpenter's trying-plane, would do just as well.

The horn protractor can, however, be rendered of equal service *without* any kind of straight-edge, by the simplest possible contrivance.

How to fit and use it.

Bore a fine needle-hole at its centre mark, and another about a quarter of an inch or so below it; through these two holes reeve a couple of feet of sewing cotton (silk is better), and knot one end; keep the knot on the *top* side of the lower hole, so that it may not prevent the protractor from lying flat on the chart, and bring the other end up through the puncture at the *central point*, and haul it tight.

To ascertain a course or bearing, it is merely necessary to lay the horn protractor with its zero line on any convenient *meridian*, sliding it towards the north or south, so that the thread when stretched may lie exactly over the two positions on the chart between which it is required to know the course, thus:—



In the diagram, *A* represents the knotted end of the thread; *B*, the centre hole through which the thread comes up; *EF*, the zero line of the protractor, laid exactly over *GH*, a meridian line; *CD*, two positions on the chart between which it is required to know the course; the line *BJCDL* represents the thread. The true course (N. 80° E. or S. 80° W.) will be found at *J*, where the margin of the protractor is cut by the thread.

The oblong ivory protractor already mentioned could be used in a precisely similar manner, but the horn one has the advantages of transparency and larger marginal divisions. Both are divided from zero at *E* and *F* up to 90° at the middle line, and when using them in the manner indicated above, the course is in each case to be reckoned *from* North or South *towards* East or West, as the case may be. Hughes' Radiograph and Cust's xylonite Station Pointer, in addition to their more legitimate uses, serve the purpose of a horn protractor. Owing to its tendency to buckle, the horn protractor should be kept between the pages of a heavy book when not in use. Xylonite (celluloid) is a better material than horn for transparent protractors.

Oblong ivory protractor.

Cust's Station Pointer.

As already explained in a previous chapter, the course between any two places on a Mercator chart *is the angle which a straight line connecting them makes with the meridian.*

True, magnetic, and compass courses.

Here seems a good place to say a few words about COURSES. So far, reference has merely been made to the *true course.* When the variation has been applied it becomes the *magnetic course;* and when the Deviation has been applied to this last, it becomes the *compass course*, or the one which is to be actually steered by that particular compass for which the deviation has been allowed. The navigator will do well, then, to bear in mind that there are—1st, the *True Course;* 2nd, the *Magnetic Course;* and 3rd, the *Compass Course.* The *true course* is the angle which the ship's fore-and-aft line makes with the Geographical Meridian; the *magnetic course* is the angle between the ship's fore-and-aft line and the Magnetic Meridian; and the *compass course* is the angle which the fore-and-aft line of the ship makes with the direction of the Compass needle on board.

Deviation and local attraction.

One word about Deviation. It is too often mixed up with Local Attraction, the two expressions being used indifferently to mean the same thing. This is wrong, as they are entirely distinct. The first named is due to causes *within* the ship herself, the latter, to *outside* influences. Remember this.

Ivory.

For laying off courses as above, the writer had made to order an ivory protractor, 10 inches by 3 inches. This size admits of good large divisions, but it is expensive. A similar one in box-wood would cost less, and probably be practically as good. The only thing that can be said against box-wood is its greater liability to chip at the edges.*

Boxwood

Ebonite.

Ebonite scales and protractors are found to answer well, though they expand and contract slightly with change of temperature, but this extreme refinement is a thing apart from our subject, and need not be considered.

* A box-wood 'Admiralty pattern' protractor, 12 inches by 3½ inches, costs 6s. To protect it when not in use, it should slide into a substantial sheath of sadler's leather, costing perhaps 2s. 6d.

CHAPTER IX.

DIVIDERS.

To give a "natty man" satisfaction in their use, dividers should be of good quality. The points must be fine, and formed of well tempered *steel* that cannot be bent or blunted. Above all, the *joint* should be good, for if not, it will be provokingly difficult to set the legs to any required distance, on account of the spring and want of uniformity in their motion. A pair of dividers with an indifferent joint, when being opened or closed, will move by fits and starts, and either go beyond the measurement required or stop short of it. The joint should also be stiff enough in its action to hold the legs in any required position without fear of alteration when handled with ordinary care. These are the things which require to be tested when making a purchase. Instrument cases always contain a key for tightening up the joints of the dividers when they work slack. What are known as Hair Dividers give *very* exact measurements, but for sea use they are *too* good, and *too* costly.

Steel points and smooth working joints

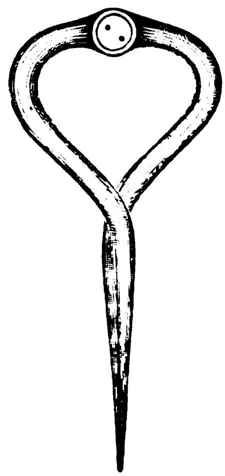
Hair Dividers

It is convenient to have a small bracket fastened on to the bulkhead over the chart table, to contain two pairs of dividers—large and small. Screw a piece of polished mahogany, 8 inches long by 3 inches broad, and ¾ inch thick, flat against the bulkhead. About two-thirds of the distance from the bottom insert a couple of brass eyes side by side. The dividers may be shipped into these, and their points rest on a ¾-in. ledge or shelf, forming a foot to the bracket. This shelf should have a moderately thin piece of india-rubber let flush into its upper surface, as a bed to receive the points without injury when dropped hurriedly into their place. To a landsman all this may seem needless trouble, but the sailor knows the value of the maxim—" A place for everything, and everything in its place." Moreover, a ship rolls and tumbles about in all directions—a house does not; so that afloat it is absolutely necessary to have safe places of deposit for other things besides glass and crockery.

Bracket for Dividers.

Pen and pencil rack.

There is a very neat little American "dodge" for holding pens, which can be purchased in Liverpool for a few pence, and is very useful. It consists of a spiral spring secured to a thin back plate, and the whole is gilded, and looks quite ornamental. The pen is held between any two parts of the spring. One of these ingenious little contrivances will contain four or five pens or pencils. It is secured to the bulkhead by a small screw at top and bottom.



DIVIDERS FOR USE WITH ONE HAND.

Dividers for use with one hand.

When a ship is rolling violently, and it becomes necessary to consult a chart, every seaman is aware of the difficulty experienced in keeping the chart and parallel ruler on the table with one hand, whilst with the other he is trying to manipulate the dividers. Some clever fellow, who has evidently been pretty often in this fix, has invented a pair of dividers *for use with one hand,* which are worthy of coming into general use. They were first shown to the writer by the captain of a schooner-yacht on the Clyde, who claimed to be the inventor. The dividers are represented above, and it will be seen that they are opened by a pressure of the palm of the hand on the circular part, which causes the legs to overlap each other and the points to separate. The closing movement is readily controlled by the thumb and forefinger, which, for this purpose, act against the palm pressure. As they are unpatented, they can be ordered from any instrument maker, and can be made with any degree of finish "*to suit the pocket*" of the purchaser.

CHAPTER X.

THE PELORUS, WITH REMARKS ON AZIMUTHS.

This valuable instrument, the invention of Lieut. Friend, R.N., deserves more than a mere passing notice. Its utility is so great that every iron ship should be provided with one.

The Pelorus is a *dumb card*—that is to say, a compass card *without needles*—made of brass, entirely unmagnetic, and not partaking in any way of the character of a compass, except that its face shows the points and degrees in the usual manner. The card is something less than 7 inches in diameter, and is mounted on gimbals, which, in conjunction with a central balance-weight suspended from the under side of the instrument, enables it to preserve its horizontality, whatever the motion of the ship may be. **Dumb card.**

The card revolves on an upright pivot like a "*teetotum.*" This pivot also serves to carry the sight vanes, which can revolve upon it independently of the card, or can be secured to it at pleasure by a large milled-headed screw surmounting the pivot. One of the uprights of the sight vane is fitted with a thread, and has a hinged mirror or speculum at its base, and the other has a coloured eye-screen, which is made to slide up and down the bar at will. A fore-and-aft mark on the inner ring does duty as the lubber's point or ship's head, and another smaller milled-headed screw on the fore part enables the card to be clamped to this mark at any desired course without fear of shifting. The whole thing is so simple, that *anyone* looking at it can understand the arrangement in less than five minutes. The apparatus is enclosed in a mahogany box some eleven inches square, and from which it is inseparable. **Description**

The patent-right having long since expired, the instrument is now constructed to order by almost any compass maker at a cost of about £3 10s. It is an improvement to have the card 9 inches in diameter. **Cost.**

Having a Pelorus, the first thing is to provide suitable stands

Stands for Pelorus.

for it in various parts of the ship, so that it may be moved from one to the other as may be found convenient. Sometimes at one position a sail, the funnel, a mast, *or an important passenger*, may be in the way of the body to be observed, in which case the Pelorus can be removed to another spot where the view is unobstructed. It will be found advantageous to fit at least four such stands—one on each side of the bridge, and a couple in the neighbourhood of the quarter-deck. A skylight, the top corner of a deck-house, or a meat safe, will answer the purpose very well. The stands on the bridge may be made in the form of a small table without legs, to bracket against the handrail. Some men go to the expense of a couple of turned teak-wood pedestals. The places selected need not be amidships—in fact, they are better when not so; but, wherever they may be, *it is absolutely necessary that great pains should be taken to ensure the fore-and-aft line of the instrument being strictly parallel with the ship's keel.*

Care in placing Stands.

How to do it.

To effect this with certainty (the instrument being in its intended position—say on the starboard or port side of the bridge), measure carefully the horizontal distance of its centre from the midship seam, and lay off this distance on the deck *both at the bow and stern end of the vessel.* At each such place erect a batten, and see that it stands perfectly plumb; the ship herself is, of course, supposed to be on an even beam; then set the North point of the card (though any other will do just as well) to the lubber line, and clamp it there by the small milled-headed screw at the fore side; release the sight vane, if clamped, and turn it so that the centre mark at the base of the upright holding the thread may also coincide with the North point; place the box by eye approximately square with the fore-and-aft line of the ship, taking care, of course, that the lubber's point is forward; now look from aft forward through the sight vanes, and slue the box slowly one way or the other till the batten at the bow is seen in one with the thread.

When exact coincidence is established, the result thus far is satisfactory; but to render it completely so, turn the sight vane half round on its axis without removing the box in any way, and set it to the South point of the card. If now, on looking at the after batten, it should be found to be exactly in one with the thread of the vane, all is well, and the fore-and-aft line of the Pelorus coincides truly with the fore-and-aft line of the ship.

The instrument must now be secured in this position by an all-round coaming about an inch high, forming a seat into which the box can at any time be shipped without further trouble. Bore a couple of holes through the coaming in each of the sides to act as scuppers. Do not take down the battens till the coaming is fitted and finished, when the line of the instrument should be *again* tested. If found to be slightly out, it can be remedied by a couple of milled-headed screws, at the side of the case, which act in opposite directions, on a sliding block carrying the trunnion of the gimbal. When this last adjustment is perfected, *the side screws must not again be touched;* and if on completing the remaining stands, their fore-and-aft lines be found not quite exact, it will be necessary to alter the *coamings* until they are so. In fixing the quarter-deck stands, the *after* battens can be dispensed with.

Direction of lubber line to be parallel with keel.

If at any time the ship should be in graving dock where some distant object can be seen, it will be very easy to test the relative accuracy of the stands by the following method:—Place the Pelorus in any one of its receptacles; clamp the North point of the card to the lubber line, and, looking through the sight vanes at the distant object, ascertain its bearing to the nearest quarter degree; remove the instrument to each of the other stands, and if the various bearings agree, it is evident that the fore-and-aft line of each station is also in agreement.

It must not be understood from this that the Pelorus gives the *real* bearing of the distant object; it merely gives the horizontal angle between the object and the ship's head. The term "bearing" is in this case used merely for convenience.

Adjustment of compass lubber lines.

To ascertain if the lubber-points of your deck compasses agree with the Pelorus, unship the cards, put a small piece of cork on the point of the pivots, and replace the cards with their North points to the lubber line; put on the glass covers; ship the azimuth instrument, and take the bearing as before.

Each compass now becomes a dumb card in itself; should there be any discordance, put up the battens and test the fore-and-aft line of the Pelorus; if found correct, it *must* be the lubber-points of the *compasses* which are astray. These are easily painted out, and ruled in afresh in their proper places. A soft black lead pencil is the best thing to do it with.

The distant object used in this operation should not be nearer than six or seven miles, unless it bear nearly ahead or astern—say a couple of points on either bow or quarter, when four or five miles will suffice. If the sun be shining, you are of course independent of everything else, since you can, if you are smart, use *it* as the distant object. The sun's bearing will seldom alter so much in the minute or so required to shift the instrument quickly from one place to another, as to introduce any appreciable error; but if extreme accuracy be required, it is an easy matter to get the exact change of bearing corresponding to the Latitude Declination, and Apparent Time from Burdwood's Tables.

The Pelorus is handy for many purposes which will be referred to hereafter, but its chief use is to ascertain the Deviation of the compass, or to set the course. Before going into the details of how this is to be done, it will perhaps be advisable to say something about Azimuths. The general practice on board ship is to observe an azimuth or bearing of the sun by compass, at the same time that the morning sights are taken: the sun's *altitude*, as found by these sights, is used to find the true azimuth. This is a round-about method, involving much needless labour, and should be abolished now that tables are published which give by simple inspection the required information.

Alt. azimuths.

It will be made clear further on, that in an iron vessel the Deviation requires to be determined pretty frequently; and to be constantly getting out one's sextant to "shoot the sun," and afterwards take the bearing, and then work up a lengthy problem, is not conducive to this end. Half the trouble and all the fuss may be avoided by using the method wherein the *time*, instead of the *altitude*, is employed. This is called the method of "Time Azimuths;" therefore, when, according to common custom, an azimuth is taken along with the morning sights, instead of laboriously figuring out the sun's true bearing by the *altitude-azimuth* problem, the hour angle (time from noon) found by the sights can be employed to take out the true bearing direct by inspection.

Time azimuths.

AZIMUTH TABLES.

Now that iron and steel have almost entirely superseded wood for shipbuilding, good Azimuth Tables are as necessary as the compass itself.

Burdwood's Tables.

In 1866, Staff-Commander Burdwood, R.N., published a book entitled: "Sun's True Bearing, or Azimuth Tables," in which is given the sun's true bearing at intervals of 4 minutes for each degree of latitude between 60° and 30° in both hemispheres. In 1875, Captain Davis, R.N., brought out an extension of these tables down to the Equator, so that at the present time the sun's true bearing can be taken out from these books for any latitude

Davis's Tables.

between 60° north and 60° south, and for any time between sunrise and sunset *excepting when the altiude exceeds* 60°. In 1896, Mr. H. B. Goodwin, M.A., R.N., published Azimuth Tables for the higher declinations (24° to 30°) between the parallels of 0° and 60°.

There are still, however, a few prejudiced enough to believe that the "old-fashioned plan," as they call it, is preferable to the tables, as the latter, in their estimation, are liable to error. These are the men who insist upon their officers working up azimuths according to the "Epitome method." They forget, or do not know, that in all calculations the greater the number of figures employed, the greater the liability to error; and surely trained computers are less likely to make mistakes than seamen, who, by nature of their calling, are not nearly so well versed in such work. During the long series of years since their publication, not half-a-dozen errors have been detected, and the Tables may now be looked upon as immaculate. By glancing the eye up and down the column, and across the page to the right and left, a mistake of any importance is detected in an instant by the want of harmony in the run of the leading figures. In working out any problem in navigation, one might just as well refuse to employ the ready-made tables of secants, sines, and tangents, and insist upon computing for one's self the necessary logarithms for each particular case.

Time azimuths preferable to alt. azimuths

Burdwood, in his preface, says:—

"Results exhibited in a tabular form have certain advantages. In these tables, for example, the value of an error in either of the three elements used in the computation is seen at once, and hence the most desirable time for making the observations, so that an error in either the Apparent Time, Latitude, or Declination, shall produce the least error in the true bearing."

Reason for preference

To use these tables, it is necessary to know the Latitude and Declination each within half a degree, and the Apparent Time at Ship within, say, a couple of minutes; but this latter depends upon circumstances, as reference to the tables will show that, under certain conditions, the sun's bearing *will not alter one degree in an hour,* and at other times it will alter a degree in three minutes. Herein, as Burdwood justly says, lies one of the great advantages of the tables.

In nautical literature, the greatest amount of competition has been in connection with the most ready means for determining the Azimuth. The navigator has consequently his pick of

Methods, Tables, and Diagrams sufficient in number to sink a ship. Excellent Azimuth Diagrams are occasionally given on the backs of the United States Pilot Charts with accompanying letterpress.

CAPTAIN WEIR'S AZIMUTH DIAGRAM.

Lord Kelvin, looking at it from a mathematician's point of view, considers it about the neatest thing of its kind ever produced, and wonders that it had not suggested itself before—apparently a repetition of Columbus and the egg.

The process of taking out the Azimuth—the Latitude, Declination, and the Hour-Angle being given—is simple and quickly done. With ordinary care, the small error inseparable from the use of diagrams will not in most cases exceed half a degree, and this is not worth consideration; but there are cases involving the centre of the diagram where the lines run into confusion, in which the error might possibly amount to a degree or a little more. These cases being confined to low latitudes and large hour-angles, would not occur every day, and on certain routes would never occur at all, so that exception to the diagram cannot justly be taken on this score.

Small errors possible.

The writer, however, is not in love with mathematical diagrams of any sort, and least of all with one for this particular purpose. Azimuths in well-conducted vessels are taken frequently, and where the same diagram is worked upon with pencil and ruler day after day by several officers, it soon gets played out. Officers' cabins are small; their table, even supposing they have one, is smaller; and diagrams which require a good large table upon which to spread them out flat and leave space at the margin for parallel rulers, do not find favour with the average merchant officer, who seldom has room enough for himself and kit, especially when two are billeted in a cabin measuring at most 6 feet by 5. Whatever the cause, experience proves that, where it does not involve more time, the preference is given to calculation. Weir's diagram is 30 by 21 inches, and should be kept flat, not rolled.

Officers' quarters.

APPARENT TIME AT SHIP.

Though the finding of the Apparent Time at Ship is a simple operation, yet few know the right way of doing it; therefore it is as well to give a couple of examples. It is premised that the longitude is known within a quarter of a degree or so.

To find Apparent Time at Ship and set pocket watch.

Write down the error of chronometer, prefixing the *plus* (+) sign if it is slow, or the *minus* (−) sign if it is fast.

Write down the Equation of Time taken from page II. of the Nautical Almanac, and correct it roughly for Greenwich Mean Time. If the precept at the head of the column says the Equation is to be subtracted from Mean Time, prefix the *minus* sign; but if to be added, prefix the *plus* sign.

Turn the longitude into time, and if it is westerly, prefix the *minus* sign; if it is easterly, prefix the *plus* sign.

If the three quantities should happen to have similar signs, add them together, and prefix the common sign; but if the quantities should happen to have *unlike* signs, add those of similar sign together, and take the *difference* between their sum and the unlike quantity, prefixing the sign of the greater. This remainder will be the amount, which (to find Apparent Time at Ship) is either to be added to or subtracted from the chronometer time, according to its sign.

Example: Jan. 16th, 1880, about 10 hours P.M., at Greenwich; required to know the Apparent time at Ship, the longitude being 64° 38′ West, and the error of the chronometer 4m. 22s. slow of Greenwich Mean Time.

		H.	M.	S.	
Longitude, 64° 38′ W..........	−	4	18	32	Having like signs, add them together.
Equation of time	−	0	10	3	
	−	4	28	35	Having unlike signs, take the difference.
Error of chronometer	+	0	4	22	
Chr. fast of App. Time at Ship	−	4	24	13	

Therefore, to find Apparent Time at Ship, it will merely be necessary to subtract 4h. 24m. 13s. from the time shown by chronometer.

To set your watch or clock, fix upon a given Time, a minute or so *in advance* of what the chronometer actually shows, to enable you to prepare; let the time by chronometer at which you intend to regulate your watch be 10h. 26m. 13s.; subtract from this 4h. 24m. 13s., and 6h. 2m. 0s. will be the Apparent Time at Ship when the hands of the chronometer arrive at 10h. 26m. 13s.

This matter of setting the wheelhouse and other clocks to Apparent Time at Ship is such an every-day necessity, that we will give one more example. In this case the longitude is East, and the Equation of Time and chronometer error are both additive.

Exam. 2: September 24th, 1880, *about* 4 P.M. at Greenwich; required to know the Apparent time at Ship, the longitude being 17° 40′ East, and the chronometer 8m. 25s. slow of Greenwich Mean Time.

		H.	M.	S.	
Longitude, 17° 40′ E.	+	1	10	40	Having like signs, are all additive.
Equation of time	+	0	8	16	
Error of chronometer	+	0	8	25	
Chr. slow of App. Time at Ship	+	1	27	21	

Here we have 1h. 27m. 21s. to be added to the chronometer time; *so, to make the even minute for the watch,* let us fix upon 3h. 54m. 39s. by chronometer; adding the above correction to this, we get 5h. 22m. 0s. as the Apparent Time at Ship when the hands of the chronometer arrive at 3h. 54m. 39s.

It will be noticed in both these examples that, in choosing the chronometer time at which to regulate the watch, the proper number of odd seconds has been allowed, so that the watch may be set to the even minute without the trouble of counting seconds, or of estimating them when there is no second-hand.

The following example shows the mode of ascertaining the deviation by using Burdwood's azimuth tables:—

TIME-AZIMUTHS OF THE SUN.

Example of finding Apparent Time at Ship.

Saturday, January 17th, 1880, about 0·45 P.M., the sun was observed to bear by Standard compass S. 15° W., when a chronometer, which was 4 m. 23s. slow of Greenwich Mean Time, showed 5h. 29m. 30s.; latitude by account, 40° 12′ North; longitude by account, 70° 50′ West; variation at place of ship, corrected for secular change, − 9½°. Here, be it understood, that Easterly variation or deviation is always represented by the plus (+) sign, and Westerly variation or deviation by the minus (−) sign.

		H.	M.	S.		
Time by chronometer		5	29	30		Declination corrected for Greenwich Mean Time, 20° 46′ South.
Chronometer slow of G. Mean Time	+		4	23		
Greenwich Mean Time		5	33	53		
Corrected Equa. of Time, page II., N.A.		·	10	19		
Apparent Time at Greenwich		5	23	34		
Longitude in time	−	4	43	20		
Apparent Time at Ship		0	40	14	P.M.	

Example of Time-Azimuth.

Open Burdwood at the nearest whole degree of latitude (40°) having the declination of the *contrary* name; this will be found at page 109. In the right-hand margin seek for 0h. 40m. P.M., and under 21°, the nearest whole degree of declination, will be found the sun's true bearing 169½°, which, according to the precept at the foot of the left-hand page, is to be reckoned from North to West.

The work now takes this form :—

☉'s *True* bearing at 0h. 40m. P.M. ...	N. 169½° W. 180°	
☉'s *True* bearing with name changed for convenience....................	S. 10½° W.	
Variation by chart	— 9½°	Applied to the right.
☉'s Magnetic bearing	S. 20° W.	Or what it would be in a wooden ship uninfluenced by iron.
☉'s Bearing by compass	S. 15° W.	
Deviation	+ 5°	Because the mag. bearing is to the *right* of the compass bearing.

It will be noticed that in applying the variation to the sun's true bearing, it is added (because Westerly), although the minus (—) sign is prefixed. The minus (—) sign in this case is only the *name* of the variation, and does not mean that the quantity following it is to be subtracted. The deviation is + 5°, which means, in like manner, that its *name* is Easterly. **Interpretation of Algebraic signs.**

In finding the *magnetic* bearing from the *true* bearing, stand in imagination at the centre of your compass-card, looking outwards towards the margin, and apply westerly variation to the right, and Easterly to the left. To find the *compass course* from the *magnetic course*, apply the *deviation* in exactly the same manner.

TIME-AZIMUTHS OF THE STARS.

Although Burdwood's and Davis's Tables are termed "Tables of the *Sun's* True Bearing or Azimuth," they may, notwithstanding, be made available for determining the true bearing of the moon, planets, and stars, when the declination of those bodies ranges between 23° N. and 23° S. On next page is a table of the mean places of stars of the 1st and 2nd magnitude included within that range for January 1st, 1902. **Azimuth tables applicable also to Moon and Stars.**

In 1897 the A B C and D tables (given further on) were so much enlarged that separate publication became necessary. They now afford a very ready means of determining the Azimuth not only of Sun, Moon, and Planets—*whatever their declination*—but of any of the 92 navigational Stars they refer to, thus constituting a material advance on anything yet produced in the way of Azimuth Tables. But they go much further, for this publication also contains rules and examples for the speedy solution of about a dozen other problems of every-day use.*

* "*Lecky's General Utility A B C and D Tables.*" London: G. Philip & Son, Ltd., 32 Fleet Street, E.C. Liverpool: Philip, Son & Nephew, Ltd., 20 Church Street

A.D. 1902.

Photo-metric Mags.	Names.	Right Ascension.	Annual Variation.	Declination.	Annual Variation.
		H. M. S.	S.	° ′ ″	″
2·1	β Ceti. (*Deneb-Kaitos*) ...	0 38 40·25	+ 3·01	18 31 27·81 S	+ 19·80
2·0	α Arietis. (*Hamel*)	2 1 38·80	+ 3·37	22 59 57·12 N	+ 17·14
1·0	α Tauri. (*Aldebaran*)	4 30 17·77	+ 3·44	16 18 44·96 N	+ 7·46
0·3	β Orionis. (*Rigel*)	5 9 49·66	+ 2·88	8 18 52·69 S	+ 4·35
1·8	ε Orionis. (*Alnilam*)	5 31 14·43	+ 3·04	1 15 51·36 S	+ 2·51
2·2	κ Orionis	5 43 6·52	+ 2·84	9 42 15·29 S	+ 1·47
Var.	α Orionis. (*Betelguese*)......	5 49 51·97	+ 3·25	7 23 20·42 N	+ 0·89
2·0	γ Geminorum. (*Alhena*)...	6 32 3·06	+ 3·47	16 28 59·27 N	− 2·84
− 1·4	α Canis Maj. (*Sirius*)	6 40 49·67	+ 2·64	16 34 52·55 S	− 4·76
0·5	α Canis Min. (*Procyon*) ...	7 34 10·38	+ 3·14	5 28 33·61 N	− 9·05
2·0	α Hydræ. (*Alphard*)	9 22 46·32	+ 2·95	8 14 0·96 S	− 15·48
1·4	α Leonis. (*Regulus*).........	10 3 9·24	+ 3·20	12 26 46·73 N	− 17·50
2·5	γ¹ Leonis. (*Algeiba*)	10 14 34·25	+ 3·31	20 20 14·66 N	− 18·12
2·2	β Leonis. (*Denebola*)	11 44 3·71	+ 3·06	15 7 11·70 N	− 20·12
1·2	α Virginis. (*Spica*)	13 20 1·74	+ 3·15	10 38 59·34 S	− 18·87
0·0	α Boötis. (*Arcturus*)	14 11 11·47	+ 2·73	19 41 32·95 N	− 18·85
2·2	α Ophiuchi. (*Ras Alhague*)	17 30 23·10	+ 2·78	12 37 51·96 N	− 2·82
1·0	α Aquilæ. (*Altair*)	19 46 0·12	+ 2·93	8 36 33·32 N	+ 9·32

Inter-tropical stars for Azimuth.

Meaning of + and — signs.

A word of caution respecting the application of the 'annual variation' of the Declination. In astronomy, North is represented by +, and South by − ; consequently, when the sign prefixed to the annual variation in the *Nautical Almanac* is +, it means that the change is in the direction of North, no matter what name the Declination may have. Thus if the Declination is North, the + sign makes it more so; but if the Declination is South, the + sign diminishes it. Similarly the — sign increases South Declination and diminishes North Declination. This is a veritable pitfall for the unguarded, more especially as this rule does not apply to certain tables given in some of the epitomes, in which these signs are used in their purely arithmetical sense of add and subtract. The above is *Nautical Almanac* style.

Star-Azimuths.

It is perfectly wonderful how few men avail themselves of the stars on a fine night, to see how their compasses are behaving. This arises principally from an ill-defined idea that any problem connected with the stars is much too difficult to be meddled with. How different are the actual facts!!

Advantages of Star-Azimuths over Sun or Moon.

Azimuths of the stars, planets, and moon, are just as easily and as quickly worked up as azimuths of the sun.

The former possess a decided advantage over the latter, inasmuch as a mistake in the working is at once detected if you observe a couple or three stars, since, having different elements, the computations are independent of each other. Whereas you may take 20 azimuths by the sun, and even though all agree, they may every one be greatly in error, through having been inadvertently worked in each case with the wrong Latitude, or Declination, or Time.

The greater the number of observations, the more the error would be confirmed, and though you might somewhat wonder at it, you would probably accept the result, and perhaps get led into danger. Now, with the stars the case is entirely different, as the one is a check upon the other.

To find the hour angle or meridian distance of a star, a planet, or the moon, you have merely, on taking the bearing, to note time by the chronometer, and proceed as follows:— **To determine Hour Angle**

1st. To the time shewn by chronometer, apply its error for the day—the result will be Greenwich Mean Time, to which apply the longitude in time, *adding* it if the longitude be *East*, and *subtracting* it if the longitude be *West;* the result will be Mean Time at Ship.

2nd. Take from the Nautical Almanac (page II. for the month) the Sidereal Time (last column), and add to it the acceleration on Greenwich Mean Time, found in the table for the purpose on page 486 of the Nautical Almanac for 1895, or Table 23 of Raper's Epitome, or page 740 herein.

3rd. Add together the Mean Time at Ship and the corrected Sidereal Time; from the sum, increased if necessary by 24 hours, subtract the right ascension of the star; the remainder will be the star's hour angle West of the meridian.

If the remainder be greater than 12 hours, take it from 24 hours, and the result will be the hour angle East of the meridian. Should the remainder be more than 24 hours, reject 24 hours, and the result will be the hour angle West of the meridian.* **To name Hour Angle East or West.**

This last part will seem somewhat confusing to the beginner, but it is nothing like so difficult as it looks. Moreover, should there be any doubt as to the amount of the hour angle, or its name, the question is easily settled by reference to Raper's Table 27, where the apparent time is given at which the principal stars pass the meridian.

Knowing more or less the time at ship when you made the observation, and by Table 27 the *approximate* time on which the star will pass the meridian, you at once see whether the star is East or West of it. But, independently of this, in actual practice **Check against mistake in naming Hour Angle.**

* To understand this, independent of any printed rule, refer to diagram on page 380.

A.D. 1902.

Inter-tropical stars for Azimuth.

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0·0	α Boötis. (*Arcturus*)	14 11 11·47	+ 2·73	19 41 32·95 N	− 18·85
2·2	α Ophiuchi. (*Ras Alhague*)	17 30 23·10	+ 2·78	12 37 51·96 N	− 2·82
1·0	α Aquilæ. (*Altair*)	19 46 0·12	+ 2·93	8 36 33·32 N	+ 9·32

Meaning of + and — signs.

A word of caution respecting the application of the 'annual variation' of the Declination. In astronomy, North is represented by +, and South by − ; consequently, when the sign prefixed to the annual variation in the *Nautical Almanac* is +, it means that the change is in the direction of North, no matter what name the Declination may have. Thus if the Declination is North, the + sign makes it more so; but if the Declination is South, the + sign diminishes it. Similarly the — sign increases South Declination and diminishes North Declination. This is a veritable pitfall for the unguarded, more especially as this rule does not apply to certain tables given in some of the epitomes, in which these signs are used in their purely arithmetical sense of add and subtract. The above is *Nautical Almanac* style.

Star-Azimuths.

It is perfectly wonderful how few men avail themselves of the stars on a fine night, to see how their compasses are behaving. This arises principally from an ill-defined idea that any problem connected with the stars is much too difficult to be meddled with. How different are the actual facts!!

Advantages of Star-Azimuths over Sun or Moon.

Azimuths of the stars, planets, and moon, are just as easily and as quickly worked up as azimuths of the sun.

The former possess a decided advantage over the latter, inasmuch as a mistake in the working is at once detected if you observe a couple or three stars, since, having different elements, the computations are independent of each other. Whereas you may take 20 azimuths by the sun, and even though all agree, they may every one be greatly in error, through having been inadvertently worked in each case with the wrong Latitude, or Declination, or Time.

The greater the number of observations, the more the error would be confirmed, and though you might somewhat wonder at it, you would probably accept the result, and perhaps get led into danger. Now, with the stars the case is entirely different, as the one is a check upon the other.

To find the hour angle or meridian distance of a star, a planet, or the moon, you have merely, on taking the bearing, to note time by the chronometer, and proceed as follows:— **To determine Hour Angle**

1st. To the time shewn by chronometer, apply its error for the day—the result will be Greenwich Mean Time, to which apply the longitude in time, *adding* it if the longitude be *East*, and *subtracting* it if the longitude be *West;* the result will be Mean Time at Ship.

2nd. Take from the Nautical Almanac (page II. for the month) the Sidereal Time (last column), and add to it the acceleration on Greenwich Mean Time, found in the table for the purpose on page 486 of the Nautical Almanac for 1895, or Table 23 of Raper's Epitome, or page 740 herein.

3rd. Add together the Mean Time at Ship and the corrected Sidereal Time; from the sum, increased if necessary by 24 hours, subtract the right ascension of the star; the remainder will be the star's hour angle West of the meridian.

If the remainder be greater than 12 hours, take it from 24 hours, and the result will be the hour angle East of the meridian. Should the remainder be more than 24 hours, reject 24 hours, and the result will be the hour angle West of the meridian.* **To name Hour Angle East or West.**

This last part will seem somewhat confusing to the beginner, but it is nothing like so difficult as it looks. Moreover, should there be any doubt as to the amount of the hour angle, or its name, the question is easily settled by reference to Raper's Table 27, where the apparent time is given at which the principal stars pass the meridian.

Knowing more or less the time at ship when you made the observation, and by Table 27 the *approximate* time on which the star will pass the meridian, you at once see whether the star is East or West of it. But, independently of this, in actual practice **Check against mistake in naming Hour Angle.**

* To understand this, independent of any printed rule, refer to diagram on page 380.

the *observed* compass bearing of the star will nearly always tell you which side it is, provided you apply to it the variation and approximate deviation. If still befogged, remember that the sextant will settle the matter: rising bodies are east, and falling bodies west, of the meridian. The preceding rule for finding the star's hour angle applies also to the moon and other planets.

Burdwood has a caution near the end of his preface, to this effect:—

Left hand column of Azimuth Tables never to be used but with Sun.

"With reference to the note at the foot of each page of the azimuth tables, as the sun in the forenoon or A.M. is East of the meridian, and in the afternoon or P.M. West of the meridian, in applying the note to indicate the bearing of a star, substitute *East* of the meridian for A.M., and *West* of the meridian for P.M."

In taking from the tables the azimuth of a star, or the moon, its hour angle must *always* be taken from the *right-hand column* of the page, under the words "Apparent Time, P.M." The subjoined examples will, it is hoped, show with what ease and certainty star, planet, and moon azimuths can be worked.

Example 1.—About 10 P.M., Saturday, January 17th, 1880, ship being in latitude 39° 20′ N., and longitude 73° 11′ W., the star Sirius was observed to bear, by Standard compass, S. 15½° E., when a chronometer which was 4m. 24s. slow of G.M.T. showed 14h. 42m. 05s. Variation at ship's place, − 7°.

	H.	M.	S.
Time by chron	14	42	5
Error	+	4	24
G. M. time	14	46	29
Longitude in time	− 4	52	44
Mean Time at Ship	9	53	45
Sidereal Time from N.A.	19	45	12
Acceleration for 14h. 46m. 29s.	+	2	26
R.A. of the meridian	5	41	23
R.A. of ∗ Sirius	6	39	54
∗'s hour angle	23	01	29W.
	24	00	00
∗'s hour angle	0	58	31E.

Declination of Sirius, 16½° S.

Open Burdwood at latitude 39°, *contrary name to the declination* (page 99), and with declination 16½° and hour angle 0h. 58m. *in the right-hand column*, look for the bearing by interpolation, which will be found to be 163¼°; this, according to the precept at the bottom of the left-hand page, is to be read from North to East. The remainder of the work is as follows:—

Example of Star-Azimuth.

True bearing of ∗ Sirius at 0h. 58m. East of meridian	N. 163¼° E.
	180°
" " " with name changed	S. 16¾° E.
Variation by chart	− 7°
Star's *magnetic* bearing	S. 9¾° E.
Star's *compass* bearing	S. 15½° E.
Deviation	+ 5¾°

TIME-AZIMUTHS OF THE MOON.

As a check upon Sirius, the moon's bearing was observed a few minutes later: and the figures are given to show the similarity of the working.

Ex. 2.—Bearing of moon by compass N. 89° W. at 14h. 49m. 41s. by chronometer. Other conditions same as in *Ex.* 1.

Example of Moon-Azimuth.

	H.	M.	S.
Time by chronometer	14	49	41
Error	+	4	24
Greenwich mean time	14	54	05
Longitude in time .... –	4	52	44
Mean time at ship	10	01	21
Sidereal time (page II. Naut. Alm.)	19	45	12
Acceleration for 14h. 54m. 05s.	+	2	27
Right Ascension of the meridian	5	49	00
Moon's Right Ascension (page x., N.A.)	0	45	00
	29	04	00
Reject	24	00	00
Moon's hour Angle........................	5	04	00W.

Moon's declin. for 15 hrs., G.M.T., from page x., Naut. Alm. = 10½° N.

Open Burdwood at page 94, latitude *same name* as the declination, and with declination 10½° and hour angle 5h. 4m. *in the right hand column*, look for the bearing, which, by interpolation, will be found to be 90½°; this, according to the precept at the bottom of the page, is to be reckoned from North to West. The remainder of the work is as follows :—

True bearing of moon at 5h. 4m. West of the meridian...	N. 90½° W.
Variation by chart..	– 7°
Moons *magnetic* bearing	N. 83½° W.
Moon's *compass* bearing	N. 89° W.
Deviation	+ 5½°

Lord Kelvin's Azimuth Mirror.

This result only differs a quarter of a degree from that given by Sirius, and proves the observations were carefully taken. The instrument used for the purpose was Lord Kelvin's azimuth mirror, which enables bearings of sun, moon, or stars to be taken with the *utmost ease and precision.* The writer has frequently taken azimuths of five different stars by it within a minute or so of each other; and when worked up, the greatest difference between any two has not *exceeded* half a degree, and sometimes the results have all agreed to the same quarter of a degree. There is no other instrument for nautical use in which such extreme accuracy is combined with such perfect ease in handling.

After the sun and moon, planets are most easily observed for azimuths, especially Venus and Jupiter, which are young moons in themselves. Among the fixed stars Sirius is first favourite, but if the silvering of the Azimuth Mirror is in good order, it is not impossible to get stars of the 3rd magnitude in cases which admit of their being picked out with certainty from among others near to them.

Observing lamp. For night work a *special* Bull's-eye lamp of *copper* is the correct thing. This lamp should be used wholly and solely for navigating work, and when employed for azimuths ought to be held well behind and above the observer, in such a manner as to concentrate the light on the far side of the compass-card. The working out of planet azimuths differs in no respect from those of the moon or fixed stars. Their Right Ascensions and Declinations will be found between pages 234 and 265 of the N. A. for 1895.

In the first of the examples just given, both the times and the declinations unfortunately necessitated interpolation in taking out the true bearings. This is a little awkward when it happens, as a certain amount of mental calculation is required to hit off the *exact* value of the bearing. But, after all, it is not a killing matter, and "practice soon makes perfect."

TIME-AZIMUTH OF POLARIS.

*'s Hr. Angle.	North Latitude.									*'s Hr. Angle.
	10°	20°	30°	35°	40°	45°	50°	55°	60°	
h. m.	°	°	°	°	°	°	°	°	°	h. m.
0 00	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	12 00
0 20	0·1	0·1	0·1	0·1	0·1	0·2	0·2	0·2	0·2	11 40
0 40	0·2	0·2	0·3	0·3	0·3	0·3	0·4	0·4	0·4	11 20
1 00	0·3	0·4	0·4	0·4	0·4	0·5	0·5	0·6	0·7	11 00
1 20	0·5	0·5	0·5	0·5	0·6	0·6	0·7	0·7	0·9	10 40
1 40	0·5	0·6	0·6	0·7	0·7	0·8	0·8	0·9	1·1	10 20
2 00	0·6	0·7	0·7	0·8	0·8	0·9	1·0	1·1	1·3	10 00
2 20	0·7	0·8	0·8	0·9	0·9	1·0	1·1	1·3	1·5	9 40
2 40	0·8	0·9	0·9	1·0	1·1	1·1	1·3	1·4	1·7	9 20
3 00	0·9	1·0	1·0	1·1	1·2	1·3	1·4	1·6	1·9	9 00
3 20	1·0	1·0	1·1	1·2	1·3	1·4	1·5	1·7	2·0	8 40
3 40	1·1	1·1	1·2	1·3	1·4	1·5	1·6	1·8	2·1	8 20
4 00	1·1	1·2	1·3	1·4	1·4	1·5	1·7	1·9	2·2	8 00
4 20	1·2	1·2	1·3	1·4	1·5	1·6	1·8	2·0	2·3	7 40
4 40	1·2	1·3	1·4	1·5	1·5	1·7	1·8	2·1	2·4	7 20
5 00	1·2	1·3	1·4	1·5	1·6	1·7	1·9	2·1	2·4	7 00
5 20	1·3	1·3	1·4	1·5	1·6	1·8	1·9	2·2	2·5	6 40
5 40	1·3	1·3	1·5	1·5	1·6	1·8	1·9	2·2	2·5	6 20
6 00	1·3	1·3	1·5	1·5	1·6	1·8	2·0	2·2	2·5	6 00

For the 12 hours before the Meridian passage (*above* the Pole) the azimuth is North and East, and for the 12 hours after it is North and West. The bearings are in degrees and tenths, and the declination has been taken as 88° 45′ N.

Table 27 of Raper gives the time of meridian passage above the Pole, and from this the hour-angle can be *estimated* at any time with sufficient nearness. Though the bearing is given for latitude 60°, it is not advisable to employ it to the northward of latitude 45°, owing to the probability of errors of observation arising from so high an altitude. There are plenty of other stars to be had, and some of them brighter.

Excepting Polaris, allusion has only as yet been made to those stars whose declinations range between 23° N. and 23° S., the limits of Burdwood and Davis; but to confine the navigator to these alone would be to deprive him of the aid of some of the brightest stars in the heavens, and so Goodwin's *Azimuth Tables for the Higher Declinations* cover from 24° to 30°, both inclusive, between the parallels of latitude 0° and 60°. This brings us to

LECKY'S GENERAL UTILITY A B C and D TABLES.*

To start with, let it be quite understood that the writer does not claim to have originated the principle of these Tables; that question is minutely disposed of in the preface to the present edition. They merely bear his name to assist in distinguishing them from those with alphabetical prefixes published by other people. Reference to the preface will shew what he *does* claim. The use of the writer's Tables is explained in Part II., chapter IX.; here it is enough to say that, by their aid, the azimuth of sun, moon, planet, or star can be taken out *almost* as quickly as from Burdwood or Davis, with this great advantage, that there is no restriction of hour-angle, nor practically of declination. **Origin of Tables.**

To shew the conciseness of the method as well as its accuracy, the true bearing of the moon (Ex. 2) is worked out afresh by the A B C Tables. *Data* as before.

Table A	+ ·204	
„ B	− ·191	
„ C	+ ·013	= S. 89½° W.

Surely this method is *simple* enough, and *concise* enough, to please anybody!! The latitude, declination, and hour-angle being given, a reasonably smart man can work the azimuth *in a few seconds under a minute.* In the case of ultra-zodiacal stars it is not necessary to know the declination, as they are specially provided for in the lower portion of Table B. ***Sharp* is the word; and *quick* the motion.**

It is important to know that when their declination exceeds the observer's latitude, stars are more than ordinarily useful for azimuths if observed at their nearest approach to the Prime Vertical.† Their change of bearing is then exceedingly slow—sometimes not 15′ in an hour—and the advantage is obvious.

* Now greatly extended and published separately.

† When the heavenly body is on the Prime Vertical the following formulæ fill the bill. Sin Az. = Sec. Lat. × cos. declin; Sin Alt. = Sin. Lat. × cosec. decl.; Cos. Hour-angle = tan. Lat. × cotan. declin,; *vide* page 468.

DEVIATION BY THE PELORUS.

How to use the Pelorus.

To revert to the Pelorus. The following is the method to be pursued to find by it the deviation of the compass on any course which is being steered at the time:—Work up position by dead reckoning from last observation; prick this off on the *Variation chart,* and note corresponding variation; correct this for the annual change by the chartlet at the north side of the sheet; set your watch to Apparent Time at Ship as already instructed; suppose it to be about 2 P.M. Then, to allow yourself sufficient time, ascertain the sun's true bearing a quarter of an hour or so in advance, say for every four minutes between 2·16 and 2·24 P.M. Apply the variation taken from the chart in order to convert the *true* bearings into *correct magnetic* ones; write these latter with corresponding times down on a slip of paper, and you are ready to begin when the time comes.

We will suppose there are several compasses in the ship (5 is not an uncommon number), and that you wish to ascertain the deviation of each by simultaneous observations. Of course you are provided with a whistle. Station a 'hand' by each compass, with instructions to note the exact direction of the ship's head when he hears the whistle.*

The Pelorus being in its stand, unclamp the card, so that it may be free to revolve on its axis; set the sight vane to the sun's "correct magnetic" bearing, corresponding to the Apparent Time by watch, and secure it firmly to the card by the large milled-headed screw on top. Tell your assistants to "look out," and the ship being nicely steadied on her course, move the card, with sight vanes attached, to the right or left till you see the sun's image reflected in the speculum and bisected by the thread; then whistle, and continue to do so, say for half a minute—so long as the sun is cut by the thread (of course it is understood that the card is not to be again moved after the first whistle). Now note the reading of the card opposite the lubber-line, and this will be the actual "correct magnetic" direction of the ship's head at the time the signal was made. The compasses, if free from error, will indicate the same thing. Should they not do so, the difference between the ship's head by Pelorus and the ship's head by compass will be the *deviation* of that particular compass on that particular course. The rule to determine its name is this:—

* An officer without a whistle is like a sailor without a knife, and every one knows what the latter is like.

If the "correct magnetic course" be to the left of the "compass course" (looking outwards from the centre of the card), the deviation is westerly, but should it be to the right of the "compass course," the deviation is easterly. **Rules for naming Deviation.**

Westerly deviation throws a ship to the left of her course, and Easterly deviation throws her to the right. Exactly the same effect is produced by *variation* of the compass, and in this respect the two are similar. **Deviation and Variation—in what respects similar.**

One of the first things done by a lad going to sea is to learn how to "box the compass;" but the old sailor's method of doing this in points, ½ points, and ¼ points, will soon be obsolete. The student of to-day, who takes a pride in his profession, will learn how to "box the compass" in *degrees*—that is to say, he will learn to tell off-hand how many degrees correspond to any given compass course reckoned in points or parts of a point. It should not take longer than an hour to master this important matter. **Boxing the Compass in degrees.**

To set a course by Pelorus, the operation is very similar to that described above. Proceed as before, except that this time the card is to be clamped not only to the sight vanes, corresponding to the sun's bearing at the appointed time, but also to the lubber's point at the correct magnetic course you wish to steer; thus, both the card and the sight vanes will be immovable. Under these circumstances you must starboard or port the helm until the thread bisects the sun's image in the speculum; when carefully steadied in this direction, whistle as a signal to the helmsman and those looking out for the other compasses, that the vessel is on her course, and to "keep her steady as she goes." **Setting course by Pelorus.**

Among the many advantages this instrument possesses, it enables the deviation of *any number* of compasses to be found by one observation, and this deviation is quite independent of the error due to any possible displacement of the lubber-lines.

The principle of the Pelorus is merely this, *that it measures the horizontal angle between the sun (or other object) and the ship's head.* **Principle of the Pelorus.**

Under certain simple conditions the unassisted eye can do the same thing, only somewhat less accurately. For example, at the instant of noon to an observer in the English Channel, the sun bears South (true). If now, the vessel is so manœuvred by her helm as to bring the sun on the port beam—say on a line with the bridge handrail, or the forward or after side of a deck-house, hatch-coaming, or skylight—it is certain that her head *must* be West (true): if the helm should be ported so as to bring the sun dead aft in a line with the masts, the ship's head must be North (true): if the helm be still ported so as to bring the sun on the starboard beam, the ship's head must be East (true): and lastly, if the sun be brought right ahead, the course must be South (true). In this way, in a small craft, the errors of the compasses might be approximately determined on the four points named.

In a ship there are many things which give true fore-and-aft lines, as well as thwartship ones, but the *intermediate* angles are wanting. The Pelorus supplies this deficiency, as it enables us to measure *any* angle between the beam and the fore-and-aft line: and this is the view which must be taken of it. You must divest yourself of the inclination to consider it a *compass;* to repeat, it is merely an instrument for measuring the *horizontal* angle between any object and the ship's head. Dumb cards *without* gimbals give incorrect—sometimes *very incorrect*—results, and should on no account be employed.

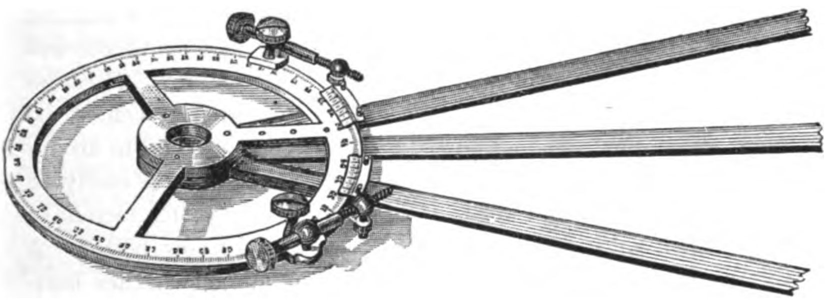
"Compass Correctors."

There are a number of instruments now before the public which profess to be "Compass correctors." It is not proposed to discuss their relative merits; but presuming them to be right in principle, which in some cases is open to question, it would be better if they were termed "Compass *course* correctors," or "Deviation detectors," as the former name is quite inapplicable. These instruments are mostly complicated; and if by any chance they get a knock or a fall, it would be difficult to re-adjust them. Whereas the construction of the Pelorus, while correct in principle, is so extremely simple in detail, that any sea-going engineer, or a handy carpenter, could "put it to rights" without much trouble. The Pelorus must not, from the similarity of names, be confounded with another invention, known as the Palinurus—so called after a famous old Greek pilot—nor with the Polaris, both of which are totally different instruments. The Pelorus will be again referred to when "Compass adjustment" comes to be treated on.

Palinurus and Polaris.

CHAPTER XI.

THE STATION POINTER.



This is an instrument that, until the publication of "Wrinkles," very few men in the merchant service were acquainted with *even by name*, and in the Navy it was seldom used, except by officers of the surveying branch. When the great practical value of the instrument is considered, this statement seems almost inconceivable. In 1893 it was supplied to all war ships, and is becoming quite popular in the better class of merchant vessels. Of the many methods for ascertaining a ship's position when in sight of a *properly* surveyed coast, none can in any way compare for ease and precision with that in which the Station Pointer figures as the chief assistant of the Sextant. So very important an instrument deserves quite a long chapter, but it is easy reading to the end, and quite in keeping with a pipe or Manila cheroot, so light up and settle down to it comfortably.

An instrument comparatively unknown.

The Station Pointer is composed of a graduated circle of brass, having one fixed and two movable arms radiating from its centre. The movable arms turn in one plane round this centre, which is common to both, and where they pass outward under the circle have verniers attached, so that the angle either of them makes with the fixed leg, which lies between them and constitutes the zero point of the circle, can be readily measured. They are made of different sizes, and more or less perfect in detail. All

Station Pointer described.

of them have clamping screws to set the movable legs to any required angle, and some, like a sextant, are fitted with tangent screws and reading microscopes. It is an *exceedingly simple* instrument to understand, and has no special adjustments or delicate mechanism to get out of order.

Of course, like everything else, the Station Pointer must be used a few times before actual expertness can be hoped for. As before stated, its use when employed in connection with the sextant is to fix a ship's position on the chart by means of two horizontal angles subtended by three well-defined objects—such as towers, lighthouses, churches, windmills, islets, capes, points, mountain peaks, hills, or other marks which may be found on the chart and duly recognised.

Practice in taking Sextant Angles.

Every aspiring officer should be as quick with the sextant in observing *horizontal* angles as he generally is in observing vertical ones—the sun's altitude, for instance. Strange to say, this is not the case. The majority of officers seem to be under the impression that the sextant can only be held in an up-and-down position, and never dream that it can just as easily be used on its flat to take horizontal angles. Clearly such men have never taken a "lunar distance," or they would know better. A sextant is useful to measure *any* kind of angle, whether horizontal, oblique, or vertical. It should unquestionably be a part of an officer's education to learn to handle his sextant so as to observe as readily and as accurately one way as the other; and to this end, therefore, during spare half-hours in harbour, or when sailing along a coast, let a couple or more officers take their sextants on deck and measure *simultaneous* horizontal angles, until by the agreement of results it is known that proficiency is attained.

Rule for holding Sextant face down or face up.

In taking a horizontal angle between two objects, stand erect and perfectly at ease, poise the sextant lightly in the right hand, with its face up, and level with the eye, do not cant the head to one side, nor bend forward—it looks awkward, and is unnecessary—and with the left hand advance the index-bar along the arc till contact is roughly established, then clamp and perfect the contact with the slow motion screw.

To secure distinct vision, it is advisable always to look *direct* at the fainter object of the two, and reflect the brighter one to it. Consequently, whenever it happens that the fainter object is to the right hand, it may be necessary to hold the sextant *face down*. There is absolutely no difficulty about this matter that cannot be overcome by a very moderate amount of practice, and, in after years, the knowledge may prove of incalculable value.

To exemplify the use of the Station-Pointer, let us imagine a vessel sailing along a weather shore beset with off-lying dangers, and desirous of hugging the coast to keep in smooth water, and gain her port,—say Holyhead, coming from Liverpool.

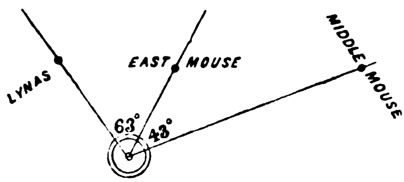
Let the reader refer to Admiralty Chart 1170B.

Buoys not reliable.

As soon as Point Lynas is passed, the captain will naturally get anxious about those bugbears to navigation, "the Coal" and "Ethel" rocks. It is true they are buoyed, but strong running tides, gales of wind and heavy seas, are apt to drag the buoys from their proper positions, and so lure to disaster, as in the case (some years ago) of the S.S. "State of Louisiana" and the Hunter rock buoy, off Larne, on the Irish Coast. Besides, the compasses may be swinging so as to make bearings inaccurate. Possibly the vessel may be iron or steel, and the deviation uncertain, or some obstacles may be in the way of the object of which you wish to get the bearing. Whatever difficulty may present itself in getting an accurate "fix" by the usual methods, none at all exists with the Sextant and Station-Pointer.

How to fix position by Station-Pointer.

Select three objects on shore which you know are laid down on the chart; for instance, Point Lynas Lighthouse, the East Mouse, and the Middle Mouse. Let an assistant measure with his sextant the horizontal angle between the first two, whilst you at the same moment measure the angle between the East and Middle Mouse, noting the time by watch for sake of reference. Having read off the sextants, take the Station-Pointer, and holding the legs *from* you, open out the left-hand one and set it to the left-hand angle, between Point Lynas and the East Mouse. In like manner set the right-hand leg to the right-hand angle, between the East and Middle Mouse. Lay the instrument down on the chart, so that the feather-edge of the centre leg may pass over the East Mouse, whilst the others pass respectively over Lynas and the West Mouse; thus,



The centre of the instrument will then represent the *exact* position of the ship, and it may be pricked on the Chart through the small hole for the purpose. The definite spots between which the angles are to be measured must be settled beforehand. In the case of a lighthouse there would be no difficulty, as the middle line of the tower, or of the lantern, would naturally present itself. For small islets or rocks it is usual to take the estimated centre, and, if close enough, to select a conspicuous rock or patch of colour to be used in common. In the case of larger islands, the right or left extremes at the water line are usually suitable; but where the rise and fall of tide is considerable, be careful not to select gradually shelving points or spits, which at low water may shew half-a-mile or so outside of what they do at high water. A glance at the chart should enable you to avoid a blunder of this kind.

Spits at High and Low Water.

As the vessel progresses Westward, fresh stations can be selected. For example, when abreast of the Middle Mouse, use it and Lynas for the left-hand angle, and the Skerries and Middle Mouse for the right-hand angle. As the "Coal" and "Ethel" rocks are approached, watch till the Middle Mouse is *in one* with Lynas Lighthouse. When in transit, *one* angle between them and the beacon on the West Mouse will fix the ship's position with great accuracy, and so on till the Skerries are rounded.

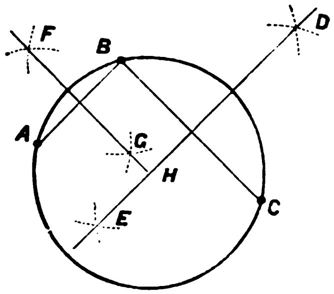
Any one who takes the trouble mentally to follow this operation as described above, will scarcely fail to see that it cannot be surpassed for *ease* and *dispatch*. Indeed, if there should be two assistants as angle-takers, whilst the 'chief' manipulates the Station-Pointer in the chart-room, the vessel's position can be *accurately* laid down on the chart in from one to two minutes from the time the objects were pointed out between which the angles were to be taken. Any one doubtful has only to try to be convinced.

The principle of the Station-Pointer.

To comprehend "the why and the wherefore" of this method, which by some is called "The three-point problem," and by others "The problem of the two circles," it is necessary to consult Euclid, but only in a very quiet way.* The first thing to understand is that *through any three points, not in a straight line, a complete circle can always be drawn, and but one*; (*vide* Euclid, IV. 5).

* Properly speaking it is a problem of *three* circles, since it includes the important one passing through the two *outer* points and position of observer. This last circle is really the key to the whole position. In the figures only two are drawn, but the student would do well to take a tracing off them and describe the third circle for himself.

Fig. 1.



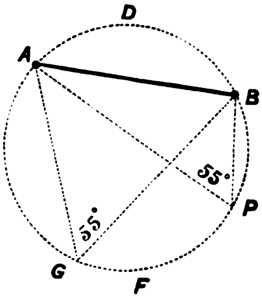
Let A, B, and C represent the points through which the circle is to be traced. Draw lines joining AB and BC.

Take any extent in the dividers greater than half the line BC, and with one foot in C describe a short arc at D and E respectively; with the same radius, and one foot in B, describe two other short arcs, cutting the former in D and E; through D and E draw a straight line. In a similar manner from A and B, respectively, describe two short arcs, cutting each other at F and G. Through F and G draw a straight line, which produced will meet the one through D and E at the point H. Then from H as a centre, at the distance of any one of the given points, as HB, describe a circle, and it will pass through the other points A and C as required. To find centre of a circle.

The student would do well to solve a few cases, until satisfied in his own mind that, no matter how the points may be placed with respect to each other, a circle can always be drawn that will pass through all three.

2nd. Another geometrical peculiarity has to be considered and understood.

Fig. 2.



Anywhere on the circumference of a circle, select two points, as A and B, and connect them with a straight line; this line is termed the chord of the arc ADB. ADB is also one segment of the circle, and AFB is another. Euclid (III. 21) tells us that from *any* point in the circumference on the same side as AFB, *the points A, B, will subtend the same angle.* (Thus the angle AGB (Fig. 2) contains precisely the same number of degrees as the angle APB). This being the case, it is evident that the circumference AFB is the locus, or path, of a constant angle, which is termed "the angle in the segment AFB," and an observer getting this angle must be *somewhere* on the circumference AFB, the size of which depends upon the angle observed. *When the observed angle is acute, he is on an arc of a circle which is greater than a semi-circle; when the angle is 90°, he is on a semi-circular arc; and, when the angle is greater than 90°, he is on an arc less than a semi-circle.*

Angle in the segment.

So far the work may not inaptly be compared to getting a "line of bearing"; but it is still necessary to fix the ship's place on this line—or, in other words, to cross this bearing with another, just in the same way as you would do with compass bearings, or as you might cut the known parallel of latitude on the chart with the North and South line of longitude, in order to definitely lay off the ship's position. Latitude *alone* would not do so, nor would longitude; but the *intersection* of the one with the other indicates the precise position. For this purpose, therefore, let us imagine another circle somewhat similar to the foregoing.

Co-ordinates.

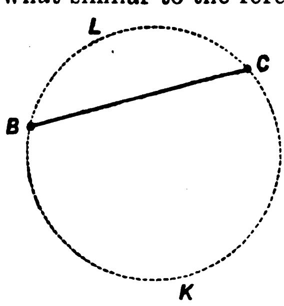
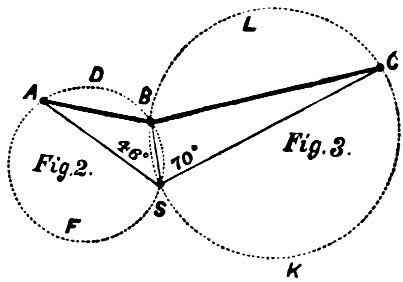


Fig. 3.

What has been said about the first, of course, holds good with this one also—namely, *that from any point in the circumference BKC, the points B, C, will subtend the same angle*, whatever that may happen to be, according to the size of the segment. Now, if the angle subtended by A, B, in Figure 2 were observed simultaneously with the angle subtended by B, C, in Figure 3, the two lines of bearing will intersect each other, and give the place of the ship.

A reference to Figure 4, backed by a careful study of the accompanying explanation, should suffice to indicate the sound foundation on which this method rests.

Fig. 4.



Let A represent Point Lynas, B the East Mouse, C the Middle Mouse, and S the ship. Let the angle observed between Lynas and the East Mouse be 46°, and the angle observed between the East and Middle Mouse 70°; draw the circles to suit these angles.

This is done by taking advantage of the fact that the angle at the centre of any circle is double the angle at the circumference on the same base.—(*Euclid*, III. 20.) We lay off, therefore, from both ends of the line which subtends the angle we have observed, the complement of that angle, or what it wants of 90°. The point where these lines meet is the centre of the circle, which is described with the distance from this centre to either end of the line, as radius. If the angle observed is more than 90°, the circle is described by laying off the number of degrees over 90°, on the *opposite side of the line* to that on which we know we are, and proceed as before. A much better way is described further on. **A simple geometrical fact.**

Now, the angle between Lynas and the East Mouse having been observed as 46°, it follows from what has been said that the ship lies *somewhere* on the circumference of the one only segment (*AFB*) containing this angle which can possibly be drawn on the given base *AB*. The position of the ship, therefore, is known to this extent, and *half* the difficulty is disposed of; but that is not sufficient. Now, by similar reasoning it can be shewn that the ship lies *also* on the circumference of the one only segment *BKC*, which with the angle 70° can be drawn on the *other* given base *BC*. She must therefore be at *S*, *the only point which satisfies the double condition*, and the only one from which we could have obtained these two angles *at the same instant.*

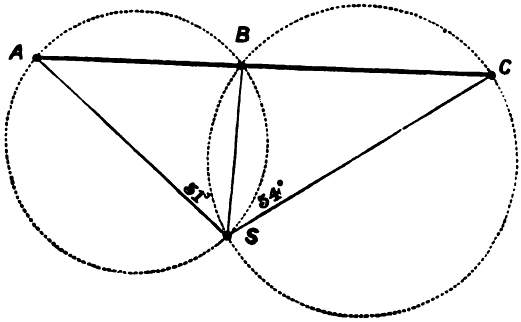
In actual practice all this is done for us by the Station-Pointer, which gives the *mechanical solution* of the problem without the trouble of drawing the circles, but the explanation of the principle upon which it is based cannot fail but be interesting to the student. "Fry's Fix," yet to come, will make it still clearer.

In order, however, that dependence may be placed in the ship's position when ascertained by these means, *it is necessary to be* *familiar with the conditions under which the circles will make good cuts.* The nearer they intersect at right angles the better; just in the same way that we try to select objects for compass cross bearings which have a difference of bearing of from seven to nine points. If the difference of bearing is small—say only 20°—the point of intersection is so acute as to be very ill-defined, and any slight error in the bearings themselves may cause a very large one in the resulting position. If the following half-dozen rules are followed mistakes need not be feared in 'fixes' with the Station-Pointer.

Half-dozen rules requiring attention.

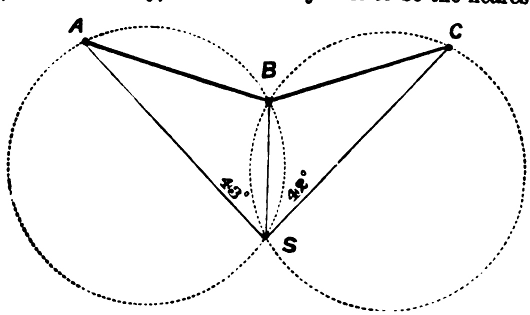
1. The three objects may lie in the same straight line.

Fig. 5.



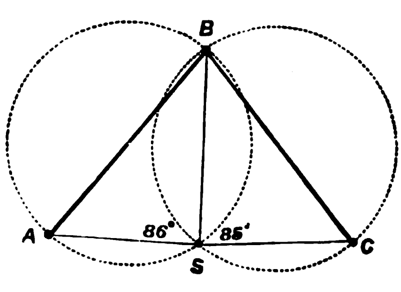
2. The three objects may lie on a curve, with the convexity towards the observer,—that is to say, the middle object is to be the nearest.

Fig. 6.



3. The three objects may be on a curve, concave to the observer, so long as the latter is either *on* or *within* a line joining the left and right hand objects.

Fig. 7.



4. The three objects may lie in a curve, concave to the observer, so long as the latter is well *outside* the circle upon whose circumference the three objects are situated. In this case the 'fix' will be good, notwithstanding the small angles.

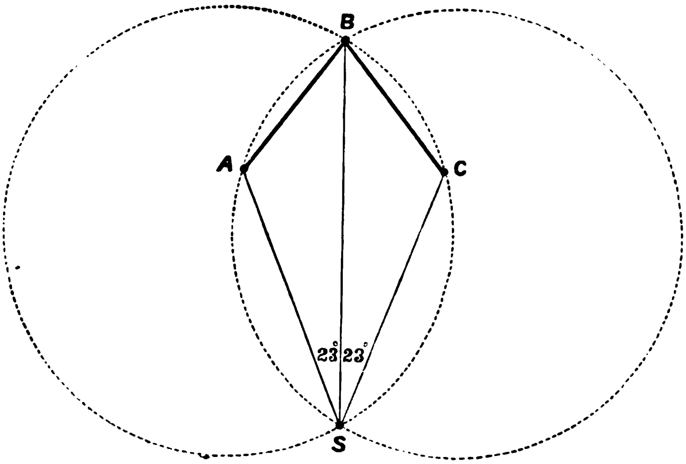


Fig. 8.

A good "Fix

5. If two of the objects be much nearer, as compared with the third, and seem, roughly speaking, about equidistant from, the observer, at whose position they subtend an angle ranging between 60° and 120°, whilst the angle between the third and middle point is comparatively small, the selection is a good one.

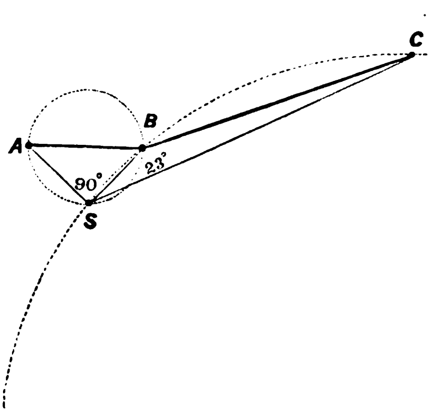


Fig. 9

6. Two of the objects may be in transit with the observer. If this should be the case, *one* angle between them and the third is sufficient. This is the best and simplest 'fix' of all. The single angle should not be less than 30°.*

* This can scarcely be included in the "problem of the two circles," but it is inserted here with the others for sake of convenience.

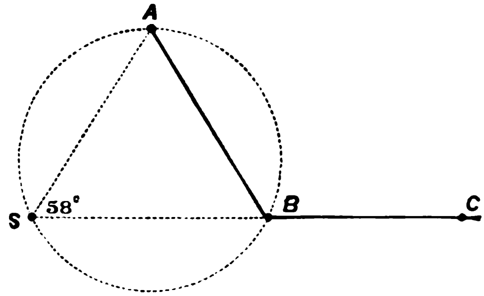


Fig. 10.

Two of the points in transit.

In this case the ship's position is fixed on the circumference of the segment *ASB*, by producing the line *BC* until it cuts it at *S*. If the observer were at any other part of the circumference, the points *B* and *C* would not be in transit; and if he kept them in transit, and advanced inside of the circumference, the angle *ASB* would at once increase. If, on the other hand, he receded from the circle, whilst keeping *B* and *C* in transit, the angle *ASB* would as quickly diminish. In this problem, the circle, as before, gives one line of bearing, so to speak, and the points in transit give the other; the intersection of these two lines of bearing of course fixes the observer's position.

Case to be guarded against.

In each of the six cases just given, the position of the observer will be fixed with greater accuracy than it possibly can be by compass bearings. On the other hand, it is necessary to guard against selecting objects lying in such relationship to each other, *that a circle joining all three would also pass through or near the place of the observer.* In such a case the position is indeterminate, as may easily be shewn by construction. For example:—

An impossible "fix."

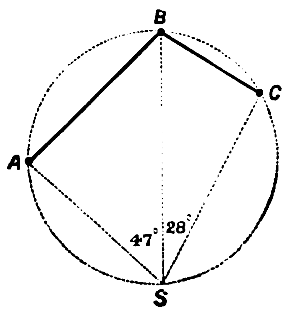


Fig. 11.

Let *S* be the observer, *A*, *B*, *C*, the points; and *AB*, *BC*, the chords subtending the angles *ASB* and *BSC*. From what has been said in previous pages, it is clear that the angle *ASB* will be found at *any* point in the segment *ASC*; and the same applies to the angle *BSC*.

(Moreover, there is no second circle to make a cut with the first). Consequently, to fix the observer's position with the Station Pointer is impossible, though in this instance Compass cross-bearings of *A* and *C* would be splendid. The chances, however, are a thousand to one against the occurrence of such a case; but others may happen verging so closely upon it as practically to amount to the same thing.

To tell value of "Fix."

Where this sort of thing *does* happen, and the circles nearly coincide, it will be found that the centre of the Station-Pointer may be moved about very considerably and the legs will still cover the three objects. On the other hand, the "fix" will be good in cases where a slight movement throws one or more of the points away from its own particular leg.

However, a little experience will soon enable anyone by the eye alone to judge if the objects are ill-conditioned, when, of course, one of the proposed points must be rejected, and another sought for in a better situation.

A seemingly objectionable case is when the middle point is near, and the other points *both* far off. Constructing the figure will in this case shew that the two circles will so nearly touch *externally* as to make the cut a very indefinite one.

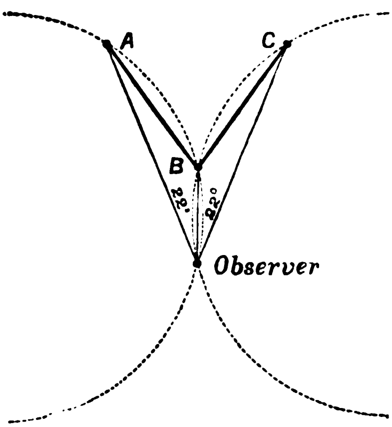


Fig. 12.

A poor "Fix" unless the third circle be drawn.

But if the two *outer* points *A C* be connected, and a circle, with an angle of 44° in the larger segment, be drawn to pass through them (*see* bottom of page 141), its intersection with the first couple of circles gives an admirable fix. The character of the cut given by this additional circle may therefore be taken as a test of the reliability of the "fix." In Fig. 11 all three circles coincide, and there is no cut whatever. The Station Pointer gives this third circle as well as the others.

It must constantly be remembered, that in using the Station

Station Pointer does not reveal ill-conditioned cases.

Pointer, it does not follow that it will of itself reveal the objectionable cases here alluded to, in which the position is uncertain. For when a position is found on the chart by the legs of the instrument passing correctly over the three points, it may not occur to the operator that, by moving it about from place to place, several others may be found where the same effect will be produced, as in Fig. 11.

Whether the position is laid down on the chart by the actual protraction of the angles and the circles, or, more readily, by the Station-Pointer, any ambiguity which would be shewn by the one method, really exists also in the other, and in the case of the Station-Pointer is all the more dangerous because it is not brought prominently into notice. Therefore, should you not be thoroughly at home in its use, it is advisable in important "Fixes" either to take a compass bearing by way of check, or a third angle to a fourth point. Having plotted the position by the first couple of angles, either leg of the Station-Pointer can be set to the last angle, and the instrument replaced on the position already found. If the legs used cover the points last taken, there can be no mistake.

Mechanical solution.

The Station-Pointer, it will be seen, gives the *mechanical* solution of this very interesting and useful problem: what has been said about it in these pages will be easily understood by the average reader; but should the "Honours" men require to exercise their brains on something a trifle stiffer, they will find a simple *analytical* solution in the Appendix, where it is out of the way of their less mathematical brethren.

The writer does not by any means congratulate himself upon selecting the case of a vessel passing round the Skerries as a good illustration of the *value* of the Station-Pointer. The north coast of Anglesea was chosen solely because that, while it sufficiently well served to shew how the instrument is used, it was probably also familiar ground to many of the readers of this book.

There are many parts of the world much better adapted to display the great *value* of the method wherein the Station-Pointer saves so much time and labour—the eastern entrance to Magellan Strait may be quoted as a good example. Before passing the First Narrows, the tide has a velocity of 8 to 9 knots at springs, and a rise and fall of 44 feet. Low and distant marks, the absence of buoys, a wide expanse of water, with intricate channels amid vast banks of sand, necessitate most careful navigation and cool judgment. Should the vessel be going *with* the tide, there is not much time for consideration, and the most expeditious, as well as accurate method, is the one which finds favour with the man upon whose shoulders rests the responsibility. Under these circumstances the Station-Pointer comes well to the front.

Advantage of Station Pointer over Compass.

Just notice the difference between it and the Compass. An angle is taken much more quickly, and very much more accurately, than a bearing. If the objects are distant, a trifling error in the bearing will materially affect the resulting position; while an error in the angle can scarcely amount to the tenth part of a degree.

Varying Deviation.

Again, when the courses are being altered pretty rapidly, to suit the windings of a channel, *the deviation is continually changing with each fresh direction of the ship's head;* and here, then, arises another element of uncertainty, to which may be added the possibility of applying the deviation the wrong way—

Its wrong application.

a thing which may happen to the most clear-headed in moments of excitement and hurry.

Further, at a most critical juncture, some obstacle may intervene between the Standard Compass and the object of which the bearing is required.

Compass a fixture.

Now, the Compass cannot be moved to any part of the ship, but the Sextant can—another very decided advantage. Moreover, as before stated, the Compass may be swinging one or more points with the motion of the ship, and this is *sure* to be the case crossing bars when there is any "run."

A compass cross-bearing cannot very well be taken by two men at the same time. It is one man's work only, and whilst taking the second bearing he has to recollect the first, and afterwards both of them, till they are finally laid-off on the chart. In the meantime the ship is speeding on. With the Station-Pointer method, three men (captain and two officers) can work together, and the angles are taken *simultaneously*. Let the officers take the angles, whilst the captain stands—Station-Pointer in hand—with the chart spread out on the table before him. As the angles are read off, they are put upon the Station-Pointer, popped down on the chart, and in an instant the ship's position is found to a nicety.

Where two objects can be got in transit, only one angle is necessary, and, consequently, only one assistant. These cases should be specially looked for and utilized.

Relative position of Angle-takers.

To avoid bungling, get into the habit of always working on an established system. There is nothing like method. For example, one officer should be told off for left-hand angles, and another for right-hand angles, and no chopping or changing permitted. Let them also stand side by side in their proper relative positions, so that they need not observe across each other, and that the mind may be trained to a sense of order.

When giving in the figures for the Station-Pointer, they should speak briefly, distinctly, and one at a time, thus:—"Left-hand angle 64° 15′," and when the instrument is set to this—and not before—"Right-hand angle 43° 22′." This saves confusion.

Both angles taken by one observer.

It may, however, sometimes happen that the Navigator will have no assistants, and so be compelled to do the whole thing himself. In this case it is a first-rate dodge to have two flat pieces of brass fitted to slide along the arc of the sextant and clamp to it at any given part. Place one in front of, and the other in rear of the vernier, so that the latter can be made to butt against either, according to circumstances. We may give these two brass outriders the name of 'stops.'

Special fitting to sextant.

To use them, proceed after this fashion:—We will suppose a case where one angle is markedly larger than the other, and getting larger all the time as the vessel sails on, and that you resolve to take it first. Dispense altogether, therefore, with the 'stop' in rear of the vernier, by clamping it at the extreme zero end of the arc, where it will be out of the way. Then, unclamping the leading 'stop,' bring it into contact with the vernier, and with the two pressed together between the left thumb and forefinger, and the sextant at the eye—slide them along the arc until the observed objects *overlap* just a trifle, then quickly clamp the 'stop,' keep the vernier firmly pressed against it, and when exact coincidence is established between the marks selected by the angle getting larger, immediately release the vernier, take the smaller angle and clamp securely—you need not lose ten seconds in doing it, unless you are very buttery-fingered indeed.

Now read off the *last* angle, and at once transfer it to the Station-Pointer, then unclamp the vernier and slide it forward against the 'stop,' which until now has been keeping guard over the *first* angle until you were at liberty to read it off. By this little stratagem it is possible for an adroit observer to measure two angles *almost* simultaneously.

Of course, if it were desirable to get the smaller angle first, you would have to employ the rear stop belonging to the zero end of the arc, and consign the other to the far end of the instrument. Very little practice is required to handle the 'stops' with expertness, and the Navigator will soon find out for himself that they are uncommonly handy not only for this, but for various other observations.*

The master of a fair-sized vessel, in any trade, ought to have no difficulty in training his officers to measure sextant angles *correctly;* that is, if they are worth their salt as *officers.* The law recognises (*vide* many recent decisions) that the master is entitled to expect intelligent assistance in Navigation from his certificated officers, and there is no lack of cases where the court has "dropped upon" officers who have failed in this respect. Most large companies embody this principle in their printed regulations.

Difference between an officer and a foremast hand.

To be unable to do such an *extremely* simple thing as measure a sextant angle, is not only discreditable to the individual, but a reflection upon the profession at large.

Cases *do* occur, however, and he should be prepared for them, where the master is thrown upon his own resources in this respect. If he does not like the method of "stops" last described, he can for a very few pounds provide himself with a "Double sextant," which enables one person to take two adjacent angles *simultaneously.* This last in italics is an absolutely essential condition of the method of 'fixing by angles,' and accordingly great stress is laid upon it.

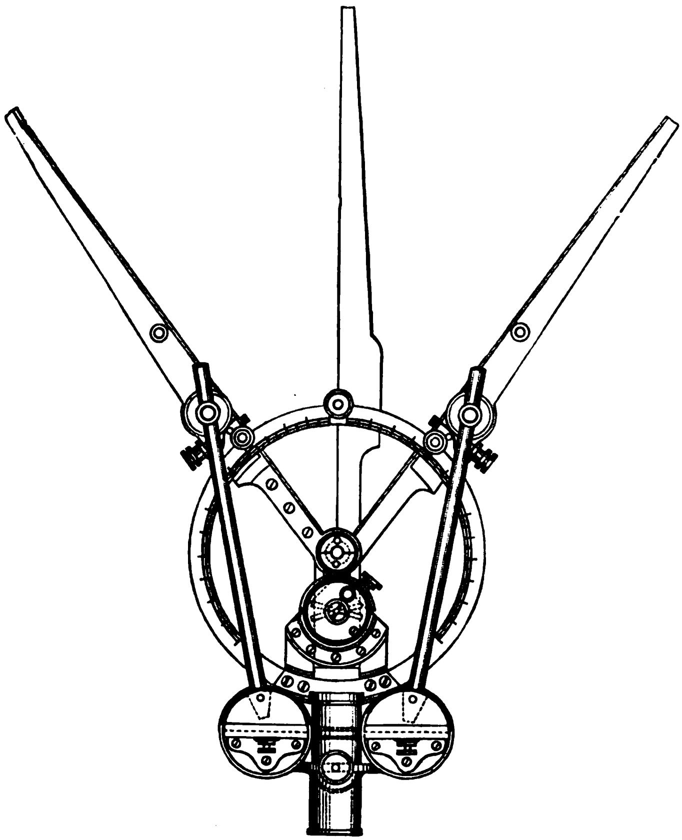
Some of those who have not investigated the problem mathematically, or are unable to do so, appear to think that because a certain small interval necessarily elapses in taking *cross-bearings,* there is no harm in a similar interval when fixing by *angles* alone. This is a serious mistake. The two methods—although in these pages a parallel is drawn between them for instruction purposes —have no connection in fact. The one is simple, the other is complex. In the case of cross-bearings two *lines of direction* are obtained (no matter how) by the angular measurement of each from a given fixed line known as the *meridian,* which line is common to both: but in the case of angles to objects there is no *line of direction;* each is the measure of an independent fixed line (the base), and the ever-varying relations of these latter to each other and to the observer *may* be such, that a comparatively small error in one or both of the observed angles will cause a displacement of the ship's position out of all proportion to the amount of such error. Figure 11, on page 146, shews that though the points A and C could hardly be better situated for fixing the ship by cross-bearings, yet *angles* between AB and BC would be utterly useless. They would merely locate her *anywhere* on the circumference ASC, which might have an extent of many miles.

Difference between angles and cross-bearings.

Therefore, any instrument which does not fulfil the condition of simultaneity should on no account be trusted. It would probably result in bringing the method of 'fixing by angles' into disrepute, which would be little short of a calamity.

The Goniograph. A special form of instrument, eminently suited to the method under consideration, was invented many years ago by the late Lieut. Constantin Pott, R.N. Not only does it permit of observing two angles *simultaneously*, but enables them at once to be plotted on the chart. It is known as the Double-reflecting Goniograph, and is in all respects a Double Sextant and Station-Pointer combined. The Goniograph *is held in the hand* like an ordinary sextant, and as soon as the angles are taken, the handle is unscrewed and the instrument put down on the chart, where it is manipulated exactly as a Station-Pointer would be. This is an instrument of precision, and now that "fixing by angles" is becoming popular, is sure to be unearthed and resume its place among the instruments of navigation.

THE GONIOGRAPH.



It should be remembered, also, that instruments which may be excellent for use on shore, where the angles can be leisurely observed without any of the disturbing influences incidental to the problem at sea, are probably totally unsuited to the wants of the navigator. For example, most men at one time or another have seen a Theodolite mounted on its tripod: the writer had a beauty—a 6-inch 'transit'—made for him by Cary, of the Strand. With this instrument set up *on shore*, the observer's position can be fixed by two suitable angles with the most *absolute* precision: in fact, it is the surveyor's mainstay; but for all that, no one in his senses would dream of using it on the unstable and ever-varying deck of a vessel in rapid motion in a rough seaway; the idea would be absurd. *It could not do it*, you might as well try to jump over the moon. The plain English of this is that instruments in every way effective in certain situations will be worse

Applicability of instruments.

than useless in others. Any angle-measuring instrument for use afloat (the compass excepted) must be held in the hand, and embody the principle of reflection in some form or another. The Theodolite cannot be held in the hand, and does not embody any principle of reflection, and is therefore of no value whatever for use at sea.

Deck-houses are a modern institution, so also is the bridge "Dodger." It will astonish some officers to learn that thirty years ago the latter was almost unknown. Now, the weather must be wild indeed, if sextant, double-sextant, or goniograph angles cannot be accurately observed under the lee of some shelter. The writer at such times was in the habit of observing comfortably (why not ?) from inside the doorway of his own room, and when an assistant was necessary, the latter planted himself inside the adjacent wheelhouse door. The bunk held the Sextant whilst the Station-Pointer was doing its share.

"Where there's a will there's a way."

Chart-table on bridge.

In going through intricate channels, it is usual in steamers to have a chart-table on the bridge, well sheltered under the weather-cloth. This impromptu chart-room is used at such times in preference to the regular one, which perhaps is inconveniently situated, and would necessitate constant running up and down the bridge ladder.

The Bosphorus, Dardanelles, Grecian Archipelago, Gulf of Suez, Red Sea, Gulf of Aden, and a thousand other places, might be mentioned where the Station-Pointer would be found extremely useful. Those who have tried it, within the knowledge of the writer, have invariably spoken in its praise, and wondered how they were ever able to get along without it.

It may be noted here that if the points used to fix by are not correctly placed on the chart, the Station-Pointer will not indicate anything wrong unless a third or "check angle" be taken and plotted. In case of non-agreement, it is certain that something is adrift. Be careful, therefore, not to use the Station-Pointer unless your chart is the outcome of a regular trigonometrical survey by competent persons. On an Admiralty sheet this information is always given.

Where the accuracy of the chart is doubtful, it is better to stick to the compass.

Tracing paper a substitute for Station Pointer.

Tracing-paper, on which a graduated circle has been printed, is at times an excellent substitute for the Station-Pointer, and in some cases preferable to the instrument itself. When, for example, the objects used for the angles are very near the observer, they will come *within* the brass circle of the Station-Pointer, and be more or less hidden by it. Plain tracing-paper may also be placed over a circle graduated on card-board, and the required pair of angles ruled in. These card-board circles can be procured from or through any optician. They are 10 inches in diameter, and divided to quarter degrees. This admits of angles being laid off by estimation to the eighth part of a degree, or even less. Windy days, however, do not suit tracing-paper when used on the bridge. Cust's Station-Pointer, above mentioned, is useful in such a quandary: it is merely a celluloid (xylonite) protractor of special design, and, like the Radiograph, described further on, the angles can be ruled on it.

Graduated circles on card-board

The right leg of a Station-Pointer does not shut close home, owing to mechanical difficulties, so it may happen that the angle observed on the right is smaller than its leg will close to. This appears to be a "Fix" with a vengeance, but a former Hydrographer—the late Captain Sir Frederick Evans, R.N.—was good enough to explain to the writer a dodge by which even this could be circumvented. Set the left leg to the small angle, and consider it *pro. tem.* as the fixed centre leg: then bring the right leg clean round the circle until its index stands at the sum of the two observed angles, when, of course, it will be doing duty as the left leg.

Brains occasionally useful.

By a system of under-cutting, the right leg is now made to close to 3°, so it will no longer be necessary to resort to the above 'wrinkle.'

A Station-Pointer with a circle six inches in diameter, and 12-inch legs in the clear, is a handy size for navigating use on board ship. Lengthening bars 9 inches long ought to be supplied in the case. By attaching these to the extremity of the legs, an increased range is obtainable when necessary. For navigating purposes it is sufficient that the circle be divided to quarter degrees: this permits of reading by estimation to 7′. The divisions should be strongly marked on brass, for convenience of rapid setting in bad lights, and no vernier or tangent screw is required. When not too finely cut, a man with fairly good eyes can set his instrument quite correctly without the aid of the small magnifying glass which is always to be found in the case. This is an advantage not to be sneezed at.

Convenient size for Station Pointer.

To acquire the knack of getting the Station-Pointer legs to

Lesson in manipulation.

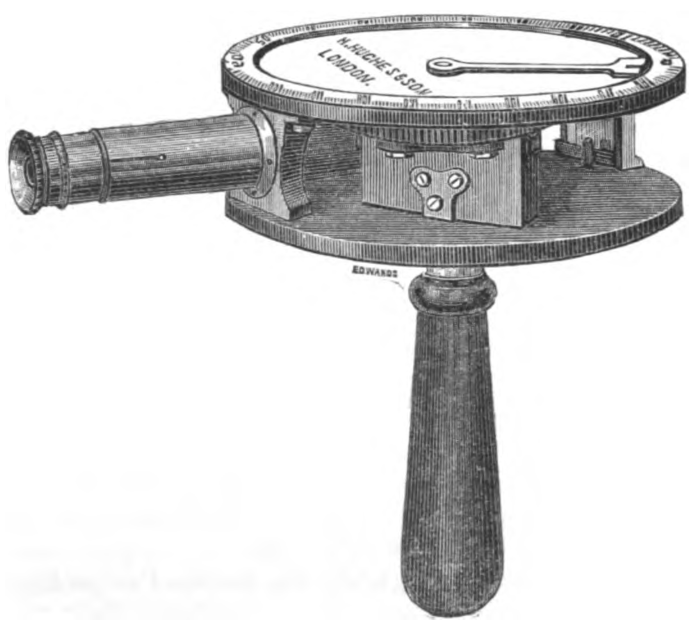
cover their respective points quickly, is not difficult. First place the bevelled edge of the central leg on the middle object of the three, keeping it on this point as a sort of pivot; then move the body of the instrument to the right or left, and slide it to and fro on the paper till the other two points are also in contact with the bevelled edges of their respective legs. The nick at the centre of the instrument will then represent the sought for position of the observer.

In handling a Station-Pointer, it should never be lifted by the legs for fear of bending them.

There is no doubt but that the Station-Pointer would more frequently be found in the possession of masters were the cost less, for it is only very recently that it has come down to the figure quoted above. Messrs. Hughes & Son, of 59 Fenchurch Street, London, recognising this, brought out a few years ago quite a handy makeshift, called the *Radiograph*. It also serves as a transparent protractor for laying off courses, bearings, &c. It certainly is a capital little instrument for the money, and to use it for six months or so as a preliminary to investing in the more perfect Station-Pointer, would give good practice at small expense. Of course great accuracy must not be expected, as the Radiograph is only divided to single degrees.

The Radiograph.

The Angle-Sextant.



Messrs. Hughes have also brought out what they consider a suitable companion to the present simple form of Station-Pointer. It is termed an "*Angle-Sextant,*" and is shown on preceding page. It is designed and intended solely for use in taking shore angles, boat survey work, and keeping station in fleet. It can be set and read off instantaneously to $\frac{1}{8}$ of a degree without the use of tangent-screw, clamp, vernier, or magnifying glass; can be placed about the deck, 'thwarts, or elsewhere, without much fear of damage.

It consists of two circular metal plates, $5\frac{3}{4}$ inches in diameter. These are framed together, and between them are mounted the Index and Horizon Glasses. The former, $1\frac{3}{4} \times 1\frac{1}{4}$ inches, has fixed to it a pinion wheel which gears into a smaller one on the index arm. These wheels being made 6 to 1, give a slow-steady motion to the index glass when the index arm is moved by hand. The circle is divided into 120°, each of which is subdivided to quarter degrees, and can be read to half that at a glance. The telescope has a clear aperture of an inch, and slides in out of the way when not in use. The wooden handle underneath unscrews, and the whole affair goes into a sling leather case. Its advantages for the work specified, as compared with the sextant, are cheapness, less liability to injury, larger field of view, and quicker reading. It will be noticed that the Anglo-Sextant and the Station-Pointer are both divided to quarter degrees, and so one is on all fours with the other. It comes to this, that, for a modest sum, one can have a most complete position-finding equipment.

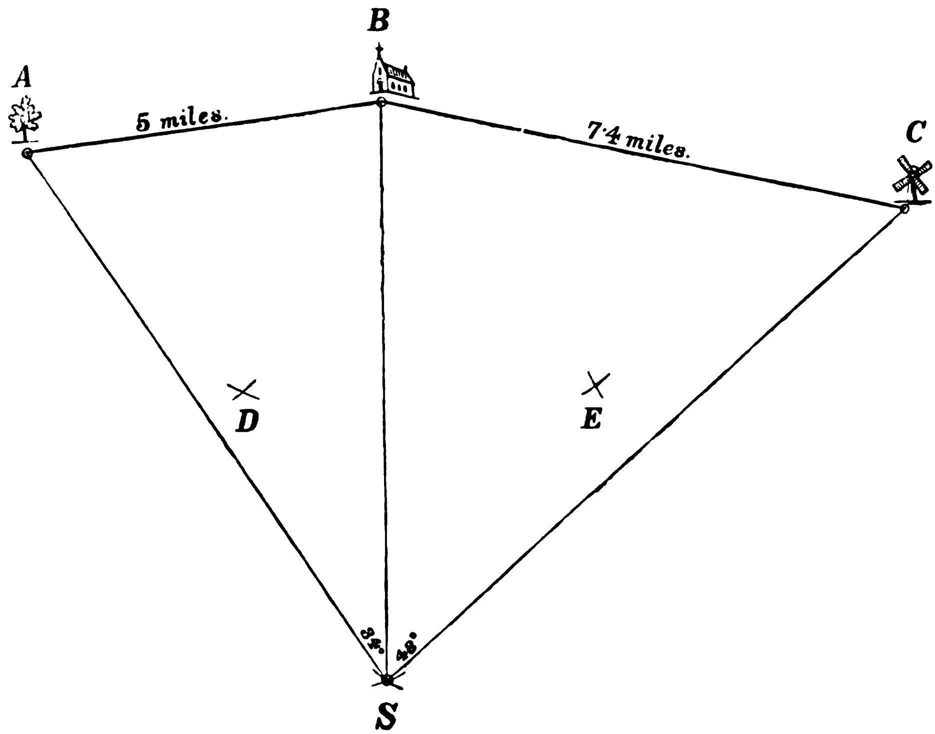
Description

Price.

The writer is indebted to the late Captain Fry, of Liverpool, for several "tips," and the following is by no means one of the least useful. The modern conjuror does the trick first, and not unfrequently tells you "How it is done" afterwards. Perhaps this will be the best way to tackle Captain Fry's very neat and practical solution of the "three-point problem." He truly remarks, in an article in the August number for 1892 of the *M. M. S. A. Reporter*, from which, by permission, the substance of this is derived, that though well-to-do masters, who take pride in their profession, will doubtless provide themselves with a Station-Pointer, there are others less lucky who, when considering "ways and means," have to study—not what they would *like to have*, but what they *can manage to do without*. For this class "Fry's Fix," as the writer has dubbed it will come in handy.

A really valuable "tip."

Fig. 13.



As shewn in Figure 13, there are three landmarks on the chart suitable for the purpose in view,—a tree, a church, and a windmill, all conspicuously visible from the offing.

From *A* to *B* the distance is 5 miles; and from *B* to *C* it is 7·4 miles. By *simultaneous* observations on board, the sextant angle between *A* and *B* is 34°; and between *B* and *C* it is 48°.

Required to fix the ship's position quickly and accurately, there being no Station-Pointer available.

Navigational conjuring. The trick is to be done without "apparatus" of any kind, if we except the very homely pencil and dividers; one leg of the latter must have a pencil-point. Of course no right-minded man goes to sea in command without a case of drawing implements: they can be had now absolutely from forty pence to forty pounds, so there is no excuse. N.B.—Those at forty *pence* are *not* recommended. Go one better, say *shillings*.

Like many other apparently difficult feats, this one of Fry's is the very essence of simplicity—in fact stupidly easy—*when you know how.*

Open the familiar Traverse Tables at one of the observed angles, say 34° as a *Course*; with 2·5, half the distance between *A* and *B* as *Departure*, the corresponding *Distance* is 4·5 miles. With this distance in the dividers, and from *A* and *B* in succession, sweep small arcs intersecting at *D*. Then from *D*, *and without altering the setting of the dividers*, sweep another arc in the direction of *S*—making it big enough this time to include the estimated position of the ship. Half the trick is now done, and very little sleight of hand required. The second half is merely a repetition, using its own figures, thus :—

The Traverse Tables have many uses.

Open the Traverse Tables at the other observed angle (48°) as a *Course*, then with 3·7, half the distance between *B* and *C* as *Departure*, the corresponding *Distance* is 5 miles. With this in the dividers, and from *B* and *C* in succession, sweep small arcs intersecting at *E*. From *E*, *and without altering the setting of the dividers*, sweep an intersection at *S*, which will be the place of the ship.*

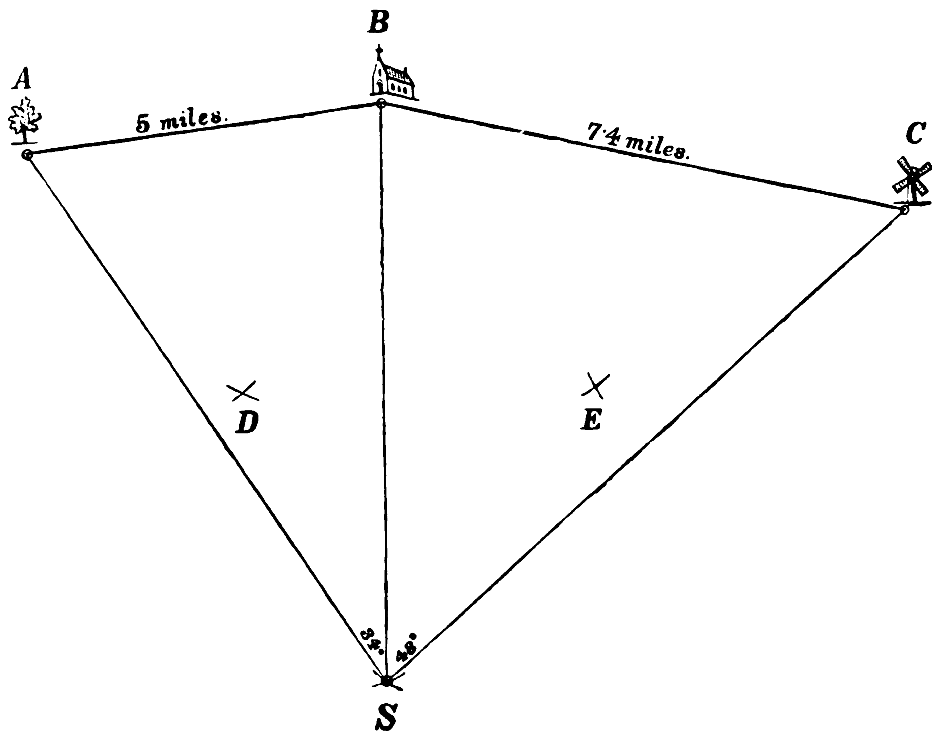
All this can be done in very much less time than it takes to describe it. A well regulated Epitome opens naturally at the Traverse Tables; and a well regulated Navigator never makes the mistake of taking the *departure* from the *latitude* column, through mooning at wrong times about "The girl he left behind him," or about the one he hopes soon to see. Now, for

"HOW IT IS DONE."

It will be sufficient to take one half of the problem, and as there is no room for the diagram on this side of the page, we must just turn over.

* For the *analytical* solution see Appendix D, but note that the scale of the diagram is different. The ship's distance from the tree is 8·86 miles; from the church it is just 8 miles; and from the windmill 9·76 miles. In all probability, however, the navigator is only anxious to fix the position of his ship on the chart, and is not concerned with the *distance* of the observed objects. (N.B.—Please pass over the fact that, to be seen so far, the marks must be pretty large, especially the tree. The given angles and distances were assumed as good enough for *theoretical* exposition.)

Fig. 13.



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"HOW IT IS DONE."

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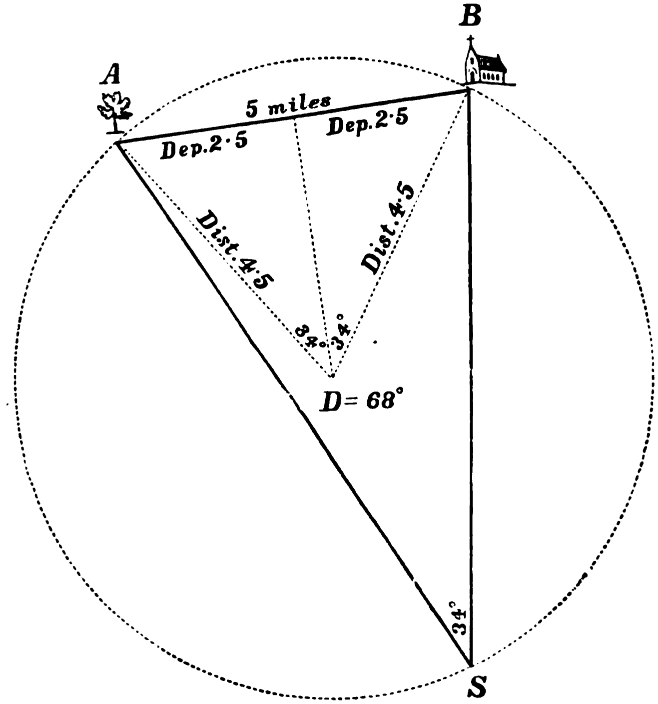

Fig. 14.

A coasting problem.

The continuous lines of Figure 14 will be recognised as the left-hand portion of the previous one; but the dotted lines contain the Key to the puzzle. In subsequent figures the circles are omitted to save confusion, though when the student is constructing figures by way of exercise, they should be drawn in full.

The whole and sole aim of this business is to discover a means of drawing a circle which shall pass through the tree, the church, *and the ship.* Only *one* circle can be made to do this, and the *size* of that circle will depend upon the observed angle—in this case 34°. But you cannot draw such a circle without knowing where to locate its centre. In the illustrations the letters *ABC* represent the shore objects; *D* and *E* respectively represent the centre of each circle; and *S* stands for ship.

Remember—for upon this it all hinges—that Euclid says "*The angle at the centre of a circle is double of the angle at the circumference upon the same base.*" But though allusion is made to angles, there is no intention of invoking the aid of any angle-measuring instrument. The beauty of the solution is that nothing out of the common is required: in a sense, it may almost be said to be non-mathematical, and yet accuracy is assured.

Since the angle subtended at S by the base AB is 34°, the angle at the centre D, subtended *by the same base*, must be 68°.

Also, the dotted lines DA and DB, being radii of the circle, must be equal, and therefore ABD is an isosceles triangle of which the base is the line between the tree and the church. If from D a perpendicular be let fall upon this line, it will divide it and its opposite angle equally. **Details of Fry's Fix.**

The isosceles triangle will then become two right-angled triangles, in both of which one side (representing *Departure*) is known to be 2·5, and its opposite angle is known to be half of 68°; or, in other words, it is 34°, the amount of the observed angle.

With these data the Traverse Tables give the *Distance* BD as 4·5. It will be remembered that this is the radius which was used to sweep short arcs from A and B respectively, their intersection at D giving the centre of the circle passing through the tree and the church, and upon *some* part of which the ship will be found; the exact spot will depend upon where the other circle cuts it. One seems to hear the reader say, Is that all? Yes, that is all!!

To work out the other half of the figure would be to go over precisely the same ground, and it is to be hoped the student can now do it for himself: if not, Figures 15, 16, and 17 will help him.

It may and probably will happen in practice that the base-line is not a whole number, and that dividing it fairly may mean two decimals: for example, let the distance between A and B be taken as 5·3; when this is divided it becomes 2·65. Open Traverse Table at 34°, and in the *Departure* column will be found 265·0, and against it in the *Distance* column is 474. Now, in each case shift the decimal point two places to the left and you get what you want, namely 2·65 and 4·74, or 4¾ miles. Should the *Distance* column only run up to 300, as is the case in some tables, the method of working will require modification; but the principle is the same. To those who know the many uses to which such Tables can be put, the advantage of a distance up to 600 is immense. **The handiness of Decimals.**

In this problem the observed angle which produces the best results is 45°, because the centre angle will then be 90°, and the centre of the circle found by the intersection of the radii is clear and unmistakable.

A property of the triangle.

The sum of the angles in a triangle equals 180°, therefore, if the observed angle be 30° the centre angle must be 60°, and the resulting triangle would be *equilateral*, for three times 60° are 180°. In this case the Traverse Tables are not needed. One has only to take the whole distance between the objects as radius, and with two strokes of the dividers find the centre of the circle. It is quite possible to wait for such cases at sea, as the angles between objects are all the time either increasing or diminishing. This and the preceding are combined in Figure 15, and speak for themselves.

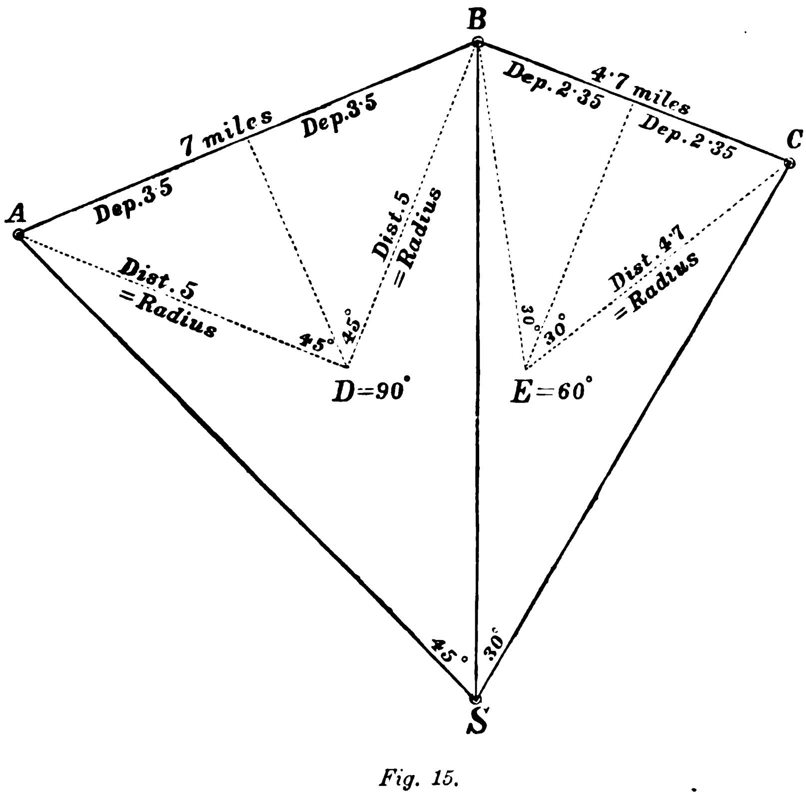

Fig. 15.

A property of the circle.

Euclid tells us that "the angle in a *semicircle* is a right angle" (III. 31). Therefore, if the observed angle be 90°, the line joining the objects must necessarily be the *diameter* of the circle, and, as such, will have 180° of the circle on each side of it. Now a line crossing a circle cannot be a diameter *unless* it passes through the centre of the circle. It follows that, in the case under notice, the centre is found "right off" without having to sweep for it.

It is of course midway on the line joining the objects; so from this point, with the distance to either object as radius, the arc for the ship's position can at once be struck.

So far the observed angle has always been acute, but, as a final possibility, it may *exceed* 90°, in which case (Euclid IV. 5) the centre of the circle would be found in the large segment on the *landward* side of the line joining the objects. Imagine the observed angle to be 120°, then the Traverse Tables would have to be entered with its supplement, which is 60°. The short intersecting arcs to find the centre would have to be struck *inshore* of the objects, but the arc for the ship's position must be struck from thence to *seaward* of the objects. In a case of this kind, the angle at the centre is the same as the observed angle. A combination of the two last is shewn in the next Figure. **Case where angle is obtuse.**

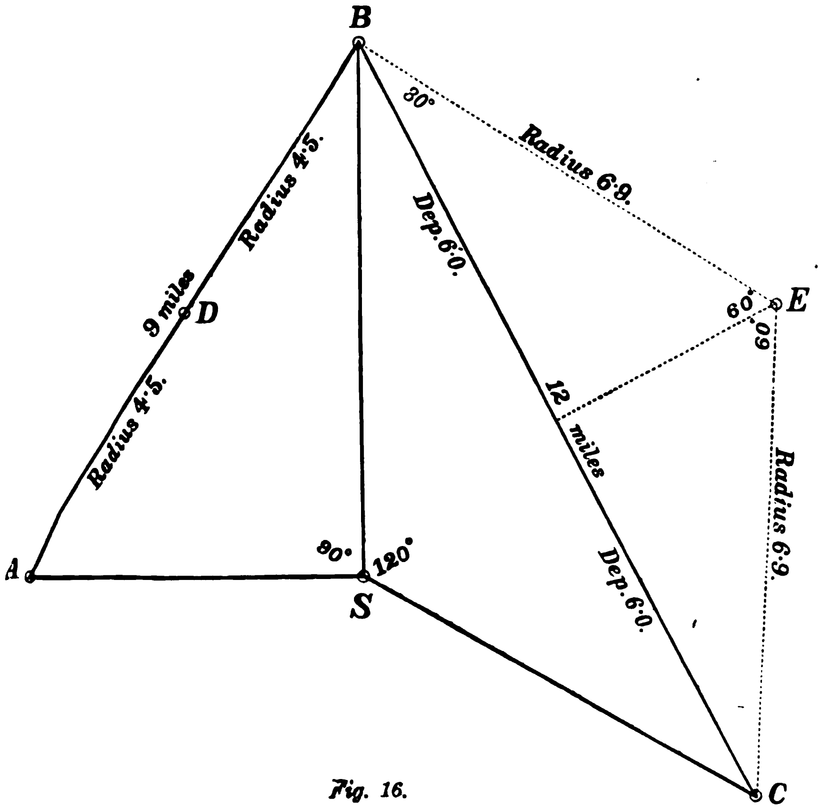

Fig. 16.

There is just one more feature to call attention to before dealing with the concluding point of "Fry's Fix." Owing to the three objects having hitherto been drawn with their concave side to the observer, as if the ship were entering a bay, the centre of each circle has always lain *within* the observed angle: but the following figure—which might be taken as representing a ship rounding a point—will shew that, with opposite conditions, the centres will lie *outside* the observed angles. In fact, as may be seen, the centre is always to be found square off from its own base, whether inside or outside.

Rule for position of centre.

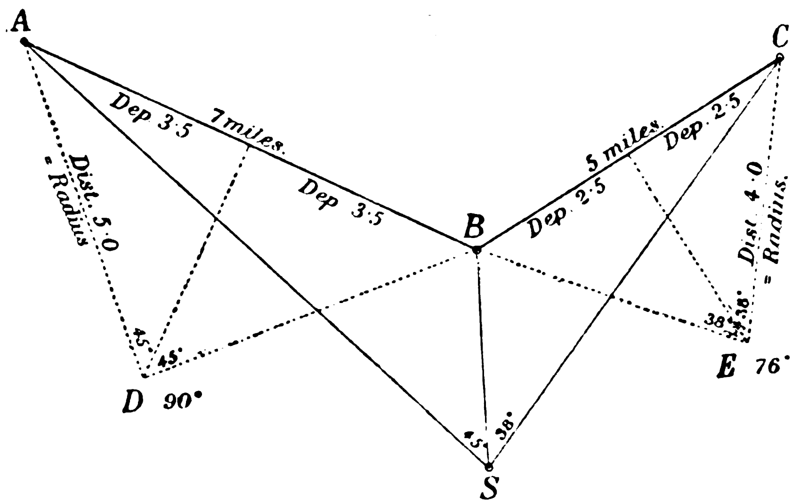

Fig. 17.

The following is an alternative plan, which possibly some might prefer. The writer would for one. Instead of consulting the Traverse Tables, use that given on next page. It is merely half the natural co-secant of the given angles. A mounted copy can be screwed up over the chart table.

An easy alternative plan.

To use it:—Multiply the quantity corresponding to the observed angle by the *whole* distance between the objects: the product is the radius required to sweep the centre of the circle, and from it the arc for ship's position as before. Can anything be easier except the Station-Pointer itself?

FRY'S FIXING FACTORS.

°		°		°		°		°		°	
4	7·17	10	2·88	17	1·71	29	1·03	42	·75	66	·55
4¼	6·75	10¼	2·81	17½	1·66	29½	1·02	43	·73	67	·54
4½	6·37	10½	2·74	18	1·62	30	1·00	44	·72	68	·54
4¾	6·04	10¾	2·68	18½	1·58	30½	·99	45	·71	69	·54
5	5·74	11	2·62	19	1·54	31	·97	46	·70	70	·53
5¼	5·46	11¼	2·56	19½	1·50	31½	·96	47	·68	71	·53
5½	5·22	11½	2·51	20	1·46	32	·94	48	·67	72	·53
5¾	4·99	11¾	2·46	20½	1·43	32½	·93	49	·66	73	·52
6	4·78	12	2·40	21	1·40	33	·92	50	·65	74	·52
6¼	4·59	12¼	2·36	21½	1·36	33½	·91	51	·64	75	·52
6½	4·42	12½	2·31	22	1·33	34	·89	52	·63	76	·51
6¾	4·25	12¾	2·27	22½	1·31	34½	·88	53	·63	77	·51
7	4·10	13	2·22	23	1·28	35	·87	54	·62	78	·51
7¼	3·96	13¼	2·18	23½	1·25	35½	·86	55	·61	79	·51
7½	3·83	13½	2·14	24	1·23	36	·85	56	·60	80	·51
7¾	3·71	13¾	2·10	24½	1·21	36½	·84	57	·60	81	·51
8	3·59	14	2·07	25	1·18	37	·83	58	·59	82	·5
8¼	3·48	14¼	2·03	25½	1·16	37½	·82	59	·58	83	·5
8½	3·38	14½	2·00	26	1·14	38	·81	60	·58	84	·5
8¾	3·29	14¾	1·96	26½	1·12	38½	·80	61	·57	85	·5
9	3·20	15	1·93	27	1·10	39	·79	62	·57	86	·5
9¼	3·11	15½	1·87	27½	1·08	39½	·79	63	·56	87	·5
9½	3·03	16	1·81	28	1·07	40	·78	64	·56	88	·5
9¾	2·95	16½	1·76	28½	1·05	41	·76	65	·55	90	·5

By way of practice, work the preceding examples over again by the last method. Fry's solutions of the "three-point problem" are original, and navigators owe him a debt of gratitude.

Funk not, but go in and win.

In concluding this chapter, the writer hopes he has fully demonstrated the value of "the three-point problem," and the instrument which renders its application so easy in practice. Let the reader not be frightened at the weak points which have been brought under his notice, since a little pains will enable him to steer clear of them, and to utilise to his own benefit an instrument which possesses so much real merit.

J. K. Laughton, Mathematical and Naval Instructor at Greenwich, is the distinguished author of an excellent little book on Nautical Surveying, which has been the cherished companion of the writer since first published in 1872. At page 145, when winding up his remarks on the use of the Sextant and Station Pointer, Mr. Laughton puts the thing so clearly and so forcibly that it is impossible not to quote him. He says:—"I have wished, in these last few pages, to show how the position of a ship, when in with the land, may be laid down; how dangers may be avoided; how a course may be steered *without* the compass. In the practice of navigation and pilotage, the attempt to do without the compass would be worse than absurd; it would be blamable in the extreme; but cases may occur, as I have endeavoured to point out, in which the sextant is a safer guide than the compass, or in which it is a most valuable auxiliary to it. To examine into these cases is the Navigator's duty; it is the Surveyor's duty to provide him with the necessary data, accurately laid down."

What Mr. Laughton says.

CHAPTER XII.

SOUNDING MACHINES AND LOGS.

In days long past, the Ancient Mariner guided his rickety craft over the ocean principally by "the three L's,"—"Log, Lead, and Lookout." When, later on, the astrolabe and cross-staff were invented, and certain astronomical data became available, another "L" (Latitude) was added to the number. In the present day, when the nautical schoolmaster is abroad, and chronometers almost go begging, this regiment of "L's" is augmented by a fifth and very important comrade, namely, Longitude. Nevertheless, the Veterans still hold their own, and are likely to do so as long as fog and clouds continue to obscure celestial objects from the anxious navigator.* The five "L's."

When a ship is stranded through thick weather, the members of the Court of Enquiry very properly lay great stress on the question as to whether proper soundings were taken or not—the omission to do so being considered a grave default. From time immemorial the Lead has been justly looked upon as one of the mainstays of Navigation, and to it, and its companion the Log, will be devoted the present chapter. Legal importance attached to Lead.

Every seaman is familiar with the ordinary "Deep-sea Lead and Line," and although it did very well for our grandsires, who were in no particular hurry, it is obliged in these fast days to make room for a better form of article.

When running up channel before a howling gale of wind, and it became necessary to ask information from the bottom as to the ship's whereabouts, every seaman knows that the operation involved much labour and loss of time, and sometimes considerable peril. The hands had to be called, sail shortened, and the ship rounded to the wind in the face of a dangerous sea. When her way was all but stopped, in obedience to the word "heave," the lead was let go from forward, quickly followed by the cry of "watch there, watch," and an experienced man on the weather Difficulty of sounding, old style.

* Captain Chas. C. Yates, Assistant, U.S. Coast and Geodetic Survey, commanding steamer *Endeavour*, writes to the Author under date October 17th, 1899, suggesting that a sixth "L" ("Lecky") should be added to make the list complete. Happy thought!! Perhaps the reader will adopt the suggestion: the Author is too modest to take it upon himself to do so.

quarter allowed the line to run through his hands till bottom was obtained. By this time the vessel had drifted to leeward, and according to the quantity of line run out, and the angle it made with the surface when being hauled in, a certain number of fathoms was deducted *by guess* from the gross amount, in order to arrive at an estimation of the true depth of water. After this, the vessel had to be kept away, and sail set, before 'the watch below' could be dismissed. Will any one wonder that masters of ships sounded as seldom as possible? Scarcely!! Especially when it is understood that to be of any service the operation must be repeated every few miles. A *single* cast of the lead is *worse* than useless, inasmuch as it may confirm an error in the assumed position of the ship.

A single cast of no value.

This necessity for repeated sounding was undoubtedly a hardship, but it can no longer be considered so, as there are now patent machines with which soundings can be taken without stopping the ship or deviating from the course. There are many varieties of these, such as Massey's, Walker's, and others, all a great advance on anything which preceded them; but it was left to Lord Kelvin to make an entirely new departure in the principle of getting flying soundings, which permitted of their being obtained with accuracy at moderate depths at any speed then or now possible. These methods, and modifications of them, are principally in favour at the present time.

What we owe to Lord Kelvin.

It would hardly be gracious or grateful to allude to improvements in sounding apparatus without referring to Lord Kelvin as the great moving spirit in the matter. By turning his brilliant scientific abilities into practical channels—a rare thing with the higher order of mathematical minds—he has, beyond possibility of question, done more than any other living man to advance the science of *Practical* Navigation. He may justly be regarded with veneration as the great 'Sea-Father' of mariners of the present age.

By substituting pianoforte wire for the old-fashioned hempen line, Lord Kelvin succeeded, on June 29th, 1872, in obtaining a cast of 2,700 fathoms in the Bay of Biscay, and this was the first successful use of steel wire for such a purpose. In 1874, he invented, and speedily perfected, a machine on this principle for deep-sea soundings, which was supplied to the cable steamer *Faraday*. Not long after came his navigational sounding machine for use with the "Compressed air depth-gauge," and this again has been supplemented by his "Depth-recorder."

It is comparatively easy to follow in a path which genius has once given the clue to, and so it happened that this new departure of Lord Kelvin's gave a "lead" to other inventors, who, following more or less closely in his footsteps, brought out sounding apparatus similar in principle, but differing in detail. This is equally true in regard to what happened with Lord Kelvin's Compass—at first regarded with more than suspicion, then sworn by. But as the Compass is still some chapters ahead, we will get back to the Sounding Machine.

The first introduced to public notice was dependent on compressed air. This, and its accompaniment of pianoforte wire, was an entire novelty; for though the famous Swedish engineer Ericsson had previously experimented in the same direction with compressed air, nothing practical came of it.

Kelvin's Sounding Machine.

The apparatus, briefly described, consists of a drum, about a foot in diameter and four inches wide, upon which 300 fathoms of steel pianoforte wire are tightly wound. To the wire is attached 9 feet of log-line, and to this is fastened an iron sinker, about twice the length of the ordinary lead, but not so thick. On the log-line, between the wire and the sinker, a small copper tube is securely seized. The lower end of this tube is perforated; the upper end being opened or shut at pleasure by means of a close-fitting cap. When ready for sounding, the copper tube contains a smaller sized glass one. This latter also is open at the bottom end, and hermetically sealed at the other. The interior surface is coated with a chemical preparation of a light salmon colour (chromate of silver). The drum is fitted with a brake cord, which, on a cast being taken, controls its speed, and ultimately arrests it when the lead touches the bottom. A pair of small winch handles wind up the wire again, and the depth is shown by the height of the discoloration on the inside of the glass tube.

Mode of action.

As the lead descends, the water is forced up the tube in obedience to a well-known law, discovered quite independently, though about the same time, by Boyle in this country, and Mariotte in France, and afterwards perfected by Regnault. It is simply that the volume of any given mass of air, or other gas, decreases in the same proportion as the pressure upon it increases. The chemical action of the salt, where it comes into contact with the salmon colour, turns it to a milky white (chloride of silver). This point of junction of the two colours, when the glass tube is applied to a graduated boxwood scale, tells the depth to which the lead descended. The sinker is "armed" in the usual way. Nothing can be neater than this arrangement. Its advantages are as follows:—

Advantages of Lord Kelvin's invention.

1*st.* Let the speed of the ship be anything up to 16 knots an hour, or even upwards, bottom can be obtained at a depth of 100 fathoms without slowing or deviating from the course.

2*nd.* Instead of requiring all hands "to pass the line along," two men and an officer are sufficient to work it under all circumstances.

3*rd.* A cast can be taken in 100 fathoms, and depth correctly ascertained in from 4 to 7 minutes, according to the speed of the ship.

4*th.* This great saving of labour and time admits of soundings being much more frequently taken than formerly, resulting in greater safety to life and property.

5*th.* A regular "*chain*" of soundings, with correct "*time intervals,*" is now not only possible, but easy; and this latter is the *sole* method which can be depended upon to give the place of the ship with any degree of certainty, since a *single* cast is not only useless in the majority of cases, but is apt to prove mischievous in the extreme.

When not wanted, the drum is kept in a tank of lime water, to preserve the wire from rusting.* A small pamphlet of directions accompanies the machine; but after seeing it once or twice in operation, the mode of working is so self-evident, as to render the instructions unnecessary. The writer has had it in use for close upon five years, and during that time has had many opportunities of testing it with most convincing results. By its aid he on one occasion, during a thick fog, brought a *new* steamer of 430 feet in length from Belfast to Liverpool, when many of the coasting boats would not venture, and of those that did a large percentage got ashore.

A feat many will remember.

BASNETT'S SOUNDING MACHINE.

During its descent, water enters the tube, as in Lord Kelvin's, and compresses the air, but it is trapped and not allowed to escape. The quantity of water thus captured indicates on a scale the depth reached. Clearly the utility of this machine largely depends upon the efficiency of the means employed to retain the water, and if these can be guaranteed to act as intended, the result

* The wire is now galvanised, so lime water is no longer necessary.

is on a par with Lord Kelvin's "Compressed air depth-gauge," except that a thicker line is used, and consequently a very fast vessel must be slowed down whilst sounding.

LORD KELVIN'S 'DEPTH-RECORDER.'

This came out in 1885, and is considered an improvement on the chemically prepared glass tubes of the prior invention. It may be used with the single pianoforte wire like the other, but should this break you are "up a tree," unless there is a second recorder on board, which in the ordinary run of merchantmen is scarcely likely, as the apparatus is somewhat expensive. With the original invention there is sufficient spare gear supplied (inexpensive) to allow of three or four breakages, which, however, can scarcely all happen in one voyage, except through gross carelessness.

However, to meet this objection, the Depth-Recorder is now supplied—for those that prefer it—with a compound wire composed of seven very fine ones. This is of course infinitely stronger, but, offering more resistance, lacks the great advantage of the single wire for flying soundings at high speeds. Next followed

COOPER AND WIGZELL'S 'SEA-SOUNDER.'

The existing form of machine was patented in 1890 as an improvement upon their previous patent of November, 1888. It is exactly on the same principle as Lord Kelvin's Depth-Recorder. In both, the pressure of the water forces a piston up the tube against the tension of a spring. A pointer shews how far the piston has moved, and indicates on a scale the corresponding depth in fathoms.

The sounding line is made of galvanised steel wires braided with hemp, and will bear a strain of nearly half a ton, so practically there is no danger of losing the instrument; but, as remarked in the case of the Depth-Recorder compound wire, it is not so good at high speeds as Lord Kelvin's single pianoforte wire; indeed Messrs. Cooper and Wigzell recommend slowing down to 8 or 10 knots on this account.

At the closed end of the Sea-Sounder there is a fairly large reservoir of air, the back pressure of which is not much affected by the comparatively small space through which the piston moves; the graduations therefore are uniform, or nearly so. This in strument is furnished with two scales of depths, one for deep soundings ranging from 8 to 100 fathoms, and the other for shallow soundings between 5 and 25 fathoms: the operation of changing from one scale to the other is simple.

Soundings are frequently very unjustly abused, and spoken about as worthless, *from want of knowledge* of how to apply them (in a methodical manner), so as to turn their indications to proper account. It cannot be too forcibly driven home that half a dozen casts taken here and there at random, will seldom fix the ship's position, and, indeed, under certain circumstances might very seriously mislead. Lord Kelvin, in his "Lecture on Navigation," mentions the *only plan* whereby the lead can be expected to determine the ship's position with any degree of certainty. He says:—

How to get useful information from the Lead.

"Take a long slip of card, or of stiff paper, and mark along one edge of it points at successive distances from one another, equal, according to the scale of your chart, to the actual distance estimated as having been run by the ship in the intervals between successive soundings. If the ship has run a straight course, the edge of the card must be straight, but if there has been any change of direction in the course, the card must be cut with a corresponding deviation from the original direction. Beside each of the points thus marked on the edge, write on the card the depth and character of bottom found by the lead. Then place the card on the chart, and slip it about till you find an agreement between the soundings marked on the chart and the series marked on your card."

Use of Tracing Paper.

The writer has practised this plan for many years, with just a slight difference, to which, on consideration, the reader will probably give the preference.

Instead of cardboard, use *tracing paper*, upon which you have ruled the courses and distances, with corresponding depths.

The advantages consist, for one thing, in the transparency of the tracing paper admitting of the chart soundings being visible in every direction underneath it, which greatly facilitates the task of making the actual soundings "tally" with those on the chart; and again, the ruling in of the courses, &c., on the tracing paper is quicker done, and, in any case, is a more familiar operation to the seaman than the use of the scissors. A meridian line should also be ruled on the tracing paper, so that, when moving the latter about on the chart, it may not get out of "slue."

The great superiority of this method, when the navigator has to fall back upon soundings to ascertain his ship's position, cannot be too much dwelt upon. With the machine just described there is no difficulty in putting it in practice. It is true that the first cost of the apparatus is considerable, but with the steamship owner—perhaps more than most men—"Time is money;" and half a day's "groping" in a large vessel will burn more coal than would pay for it twice over. This is putting all sorts of contingencies due to detention on one side. Every one in the business knows that the loss of a certain tide may entail (directly as well as indirectly) an extra expense of three or four hundred pounds on large steamers running on schedule time. The cost of a sounding machine is very insignificant in comparison with this. **Value of Sounding Machine.**

The other kinds of sounding machines previously in vogue vary in certain minor details, but they nearly all depend upon the principle of the rotating fly. A small cylinder, protected by brass guards, is caused to rotate in its descent through the water by vanes or blades set obliquely to its axis; this communicates motion, by an endless screw or worm, to a train of toothed gearing. On the machine reaching the bottom, an arm falls and locks the rotator, so that it cannot revolve in the opposite direction as it is pulled to the surface. An index points to figures on a graduated dial, which indicate the depth of water reached. **Principle of previous Sounding Machines.**

These instruments are very good, but they nearly always possess what may be termed an index-error—that is to say, they either show too much or too little. When quite new they are generally correct, but, through wear of the working parts—*or more likely from knocks under the counter in hauling in*—they seldom long remain so. However, their error is easily determined, and an account of it, with date when determined, should be kept in a small pass-book in the box containing the machine. **Sounding Machine Index-error**

To ascertain the index-error: any time when the vessel is at anchor in tolerably deep water, the depth indicated may be compared with the actual depth found by a carefully marked lead-line; should the depth be under 20 fathoms, it is a good plan to take several measurements by the machine *without resetting it*, and divide the last reading by the number of casts; or, what is pretty much the same thing, multiply the actual depth of water by the number of casts, and compare the result with the last reading. **To ascertain it in harbour.**

For instance, in 20 fathoms of water, let five casts be taken without resetting the instrument. Now, it is clear that if it indicated truly, the last reading should be 100 fathoms; but **To ascertain it at sea.**

supposing it to be 95 fathoms instead, then the index-error is about five per cent., to be added to any soundings which may be taken *until the index-error is again ascertained.*

A still better plan may be resorted to at sea if any temporary derangement of the engines of a steamer necessitates a short stoppage, or in a calm if a sailing ship.

Index-error.

Set the sounding machine to zero, and attach it to the deep-sea lead and line in the usual way. Make the other end of the line fast to the taffrail, with just enough drift to allow the 100 fathom mark to touch the water when the cast is taken; make the line up into four or five coils of 20 or 25 fathoms each, and let as many men as there are coils hold them over the stern; upon a given signal, let go the lead simultaneously with the first coil, and immediately after, each of the others, taking care to drop them on their flats, proper side up. If the vessel's way is entirely stopped, the machine will of course descend vertically to a depth of 100 fathoms, and should register that water; if not, the difference will be the percentage of error. If there be time, repeat the operation once or twice, and take the mean result as the index-error.

Either before, or immediately after, *test the measurement of your lead-line.*

Modes of sounding in sailing ships and steamers.

The foregoing is a correct description of the mode adopted in steamships to sound with these instruments. Should the water be deep, the vessel is slowed down. In sailing ships the machine is usually cast over from forward, and the men with the coils are stationed at intervals along the ship's side in the ordinary way; but they should be instructed *at once* to let go their coils, and not try for bottom, as they would do with the common deep-sea lead. In steamers the men are stationed across the taffrail, and the coils are dropped over the stern to prevent the bight of the line getting foul of the propeller.

The deep-sea line should be kept on a suitable reel, and protected from wet by a painted canvas cover. When there is no reel, it is handy to coil the line in a small tub, with a hole in the bottom through which to pass the inboard end, so that it may be made fast to a belaying pin, or hitched to a backstay.*

Deep-sea lead to be always at hand.

The common deep-sea lead and line ought to be kept on deck ready for use at a minute's notice. Should the vessel at any time appear to be passing through shoal water not marked on the

* Before marking, tow the line astern for some hours with a heavy lead fast to it.

chart, stop her at once, and *arm the lead* before sounding. Do not make certain that you have reached the bottom *unless an unmistakable specimen of it comes up.*

"VIGIAS."

In the event of falling in with a new danger, such as a rock awash, it is *the imperative duty* of the discoverer to satisfy himself and others on board that it is *really* what they have taken it to be. It should be examined by boat as closely as possible, and soundings taken round it with the hand lead, while the ship, at a safe distance, sounds with the deep-sea lead. If possible to land on it, do so; and chip off a piece of the rock, to make assurance doubly sure.

Nature of special dangers to be verified.

In searching for a "vigia," it is difficult to say when its existence is to be considered as disproved. Although experience shows that nine out of ten of the bugbears and blots formerly to be found on Oceanic Charts had been mistakenly placed there from reports of floating whales, wrecks, and patches of vegetable growth taken for discoloured water over a bank, &c.; still the apparently astounding manner in which rocky heads do rise from very deep water, must always make us careful of hastily assuming that no danger exists near a given locality, simply because it is known that the depths in the neighbourhood are very great. St. Paul's rocks, near the Equator, may be quoted as a good example of this kind of thing. Were they a few feet *below* water, instead of *above* water, it would be no easy job to find them. The Avocet Rock in the Red Sea was an example of this kind of difficulty.

THE "BLUE PIGEON."

The Hand Lead, or "Blue Pigeon," is *not* by any means as familiar to the seaman as it ought to be. It is a disgrace to the Mercantile Marine that so many men calling themselves Able Seamen know not how to use it. If officers would but practise their men and boys at this occasionally, instead of putting them to knot rope-yarns for spunyarn, or pass away the watch lazily making sennit, fewer ships would get ashore through unreliable leadsmen. Spunyarn can be purchased at a ship-chandler's, but good leadsmen cannot.

Hand lead—necessity for practice.

For use in shallow rivers, such as the Plate, where the vessel is navigated almost entirely by the hand lead, it is convenient to have a small nicely shaped lead, about five pounds in weight, attached to 12 fathoms of cod-line. The line is marked in the

Shoal-water lead.

usual way, except that at 4 fathoms there is a manila or coir rope-yarn.

It is unfortunately too common for pilots, when they come aboard off a harbour's mouth, to order the man out of the chains, saying they do not want the lead. The writer never permitted this, and squared the matter with the pilot by telling him that he required the lead hove for his own satisfaction, and to give the man a chance to practise.

Unlit channels—how to navigate.

In navigating an unlit and unmarked channel, where the water shoals pretty gradually on each side, the safest plan is not to attempt to steer a mid-channel course, but to zigzag it, keeping a lead going in both chains. By this plan *you can tell which side you are on*, and how to put the helm to avoid the danger.

Also, when obliged to thread intricate channels between coral reefs, wait, if possible, till the sun is astern or behind you, and direct the course of the ship from the fore-topgallant yard or some such lofty position.

THE SUBMARINE SENTRY.

Maximum speed of ship.

This is a splendid invention. Its object is to provide a continuous 'under-water look-out'—involving no special labour, and requiring but little attention—which will give instant warning when the water shoals to a less depth than it is set for. The speed may be anything up to 13 or 14 knots. When the ship's position is uncertain, it is scarcely likely that, in foggy weather and near land, this speed will be exceeded.

Briefly, the machine consists of an inverted wooden kite, slightly over 3 feet in length, and weighing about 15 lbs. This is towed from the stern by a galvanised pianoforte wire, only ·067 of an inch in diameter, but strong enough for all that to withstand a strain of 1,000 lbs. At 13 knots the stress on the wire is about half this.

Air and water kites.

Just as an air kite rises by the oblique pressure of the atmosphere, so a marine kite sinks by the oblique pressure of the water. On striking bottom, the blow acting on a projecting trigger releases the slings of the 'kite,' and causes it at once to rise to the surface and trail in the wake of the vessel. At the instant of striking, the sudden loss of tension in the wire sounds a gong attached to the winch on board.

Sounding-box.

Whilst the 'Sentry' is on the look-out, the vibration of the wire causes a continuous rattle in a sounding-box, and the cessation of this noise gives an additional indication (if any were wanted) when the 'Sentry' has struck the ground. The *vertical* depth of the 'kite' at any time is indicated on the dial-plate of the winch.

Two kinds of 'kites' are issued with the machine; the one painted black is for depths down to 30 fathoms, and will be more commonly used: the other, painted red, is designed for use at depths between 30 and 45 fathoms.

It might be supposed that alterations in the vessel's speed would affect the towing depth of the 'Sentry'; but this is not so: the depth is practically unchanged by any variation of speed between 5 and 13 knots. As this is a point of the very utmost importance, it may be well to look for an explanation by considering the forces which are acting when the 'Sentry' is being towed. The weight of the 'kite' is made equal to, and is therefore neutralised by, its own buoyancy; and the weight of the wire is negligible compared with the forces due to the motion through the water. The forces therefore which remain to be considered are only: (1) the fluid pressure on the 'kite'; (2) the fluid pressure on the under side of the wire; and (3) the tension of the wire, which is the result of (1) and (2). **Effect on Sentry by alteration in speed.**

Now, pressures due to fluid motion vary very nearly as the square of the velocity. If therefore, say, the velocity of the ship be doubled, the forces (1) and (2) will each be multiplied by 4, and their resultant—the tension—will also be multiplied by 4; the three forces will all be changed proportionally, and there will be no change in the directions in which they act. It is found in practice that a change of speed from 5 to 13 knots does not cause a variation of more than half a fathom in 30 in the depth of the 'kite.' It is also found that, on duty, the 'Sentry' does not yaw about as an air kite sometimes does, but that, on the contrary, it takes up its position and maintains it as steadily as a church. **Steadiness when towing.**

The 'Submarine Sentry'—a capital name for it—is the outcome of experiments conducted at sea by Mr. S. H. James, C.E., of London. Before the instrument was perfected, these experiments had extended over two and a half years. The idea is not new by any means, but to Mr. James belongs the credit of being the first to solve the problem *successfully*. It can be handled by one man.

THE COMMON LOG.

Logs, whether patent or common, are entirely unsatisfactory in their indications of speed. The common log does not do so **Common log not reliable.**

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Common log not reliable.

badly up to 10, or perhaps 11 knots, but after that it is not to be depended upon. No two men heaving the log will make the same report, *if* the ship's speed exceeds 12 knots. The short log glass runs 14 seconds, or one second per knot for a ship going 14 knots. Now a second is a very short space of time, and it is not difficult to see that, in consequence, a vessel may very easily be overlogged or underlogged to at least the amount due to this interval. This may be owing solely to the dulness of perception of the man who holds the glass, and does not take into account the possible error of the glass itself, the log-line, the heave of the sea, or the want of skill on the part of the man heaving the log. It is true all these things *may* act in opposite directions, and neutralize each other; but they may *not.*

Again, the common log fails in not affording a *continuous* record of the speed, so that a vessel may go anything during the interval, usually two hours, which elapses between two successive trials. This is not much felt in a steamer, where the rate of speed is not likely to alter greatly in such a short time; or if it does, it can be allowed for. But in a sailing ship it is a serious drawback, and in this respect the patent log has the decided advantage.

PATENT LOGS.

The patent log—its defects and their causes.

Patent logs depend upon the principle already explained in connection with the sounding machine, but their results, from a variety of causes, are less reliable in affording a correct knowledge of the distance run, than those of the sounding machine in giving the true depth. In the first place, they are more constantly at work, and so wear out sooner; they are liable to be fouled by seaweed, waste, or ropeyarns, &c., thrown overboard from the ship; their indications in a head sea are usually different to those in a following sea, and depend also upon the length of tow-line; they are frequently damaged by blows against the counter in hauling in, and to this they are more often exposed than the patent sounding machine; lastly, there is no satisfactory way of finding their index-error.

Off soundings no form of log will indicate current.

In channel, where there are points of land the distance between which is known, there is usually a tide which renders abortive any attempt to adopt such a mode; and in mid-ocean, there are surface or drift currents depending upon the winds, so that it is next to impossible to arrive at any definite conclusion. In fact, there is no known instrument at the present time which *correctly* gives a vessel's speed *over the bottom* in deep water. Even supposing a patent log to indicate correctly the speed *through the water*, what about current or tide? There is no *deep-sea* log which indicates current; but in shallow rivers like the Plate, what is known as the "Ground log," gives fairly approximate results as to its amount, provided the speed is not too high, and care is exercised in heaving it.

"GROUND LOG."

Ground log—its description and use.

This is simply the common log-line with a hand-lead substituted for the log-ship. When the log is hove, the lead lies on the bottom without dragging, and so gives the speed *over the ground;* and in hauling it in, the *trend* of the line at starting is supposed to shew the *direction* of the current; but this latter is not correct except in a very broad sense indeed, and the writer strongly counsels the navigator not to place the slightest dependence upon it. It is evident that, to get the correct direction of the current, the ship must make a mathematically straight wake during the operation, and her speed must be slow. In a small vessel, with a lumpy sea, the indicated direction would not be worth much, though the speed might be pretty near the mark.

In using the Ground log, some people go to the trouble of fixing a crutch on the taffrail in which to put the line, and underneath it, a painted semicircle of points of the compass, to show the direction; but this, as already stated, is labour entirely thrown away.

TAFFRAIL LOGS.

The "Cherub" Taffrail log.

T. Walker and Son have introduced a patent Taffrail log, which can be consulted and reset as often as necessary, without the trouble incidental to those in which the whole apparatus is towed astern. It has a novel feature of considerable value: by the interval between two consecutive strokes of a small bell, coupled with a short and very simple sum in proportion, the *rate* of speed at any desired moment is found in a few seconds.* It is practically free also from the danger of being damaged in the operation of hauling in, as this latter need only be done once at the end of the passage, nor can it be swallowed by a shark.

In the Taffrail log, the registering portion is secured to the rail, and motion is communicated to it by the rotator through the medium of a long tow-line. There is no doubt this is very convenient, but it appears to the writer that unless great care is exercised in repeatedly oiling the works they would be liable to

* See Appendix H.

heat at a high rate of speed.† As the 'harpoon' and other similar logs are towed bodily in the water, and so get plenty of "fisherman's grease," they are not exposed to this danger. As a matter of fact, there are no patent logs yet invented which will stand the wear and tear for any length of time. In slow vessels they will of course last longer than in fast ones. Unless used only on special occasions, such racers as the *Philadelphia*, *Majestic*, or *Lucania* very quickly put them out of order.*

Trimming sail.

From this the reader must not conclude that they are to be abandoned as altogether useless. The writer merely wishes to urge upon the navigator the imprudence of trusting too implicitly to their indications at critical times. Patent logs are more useful in slow steamers than fast ones, and still more useful in sailing ships than steamers. Young officers not unfrequently trim the yards too fine, and if the strokes of the bell of the Taffrail log were timed before and after trimming, the difference would be apparent. The same applies to carrying an injudicious press of sail, as it often happens—especially in full-bowed vessels—that they go faster and steer straighter when "shortened down" a bit; an advantage to everybody except ship-chandlers and sailmakers. To avoid unnecessary wear and tear, patent logs should only be used when "in with the land." It is found to be a good plan to wrap the line—about a fathom in advance of the log—with sheet lead, to keep the latter from jumping out of the water. †

Instance of patent log spoilt by sand ballast.

The writer once knew a patent log to be totally spoilt by sand getting into it. The steamer was bound to an American port in ballast, and, as is usual, got rid of a quantity of it overboard during the last two days before arrival. The log was allowed to tow, as no one imagined the sand could reach it, but when it was hauled in at the end of the watch, it was found to be perfectly choked with it; and as the oil-holes, &c., were closed, the puzzle consisted in how the sand reached the interior. The log was duly cleaned, and on the homeward passage tested, but it showed about 30 per cent. too much distance, and was in consequence put away as worthless.

To ensure the best results, a 'harpoon' log should be towed

* The writer used one of Walker's Taffrail logs in a 13-knot steamer with very satisfactory results: for nearly a year the index-error kept between + 2% and 4%, but the log was only towed for 500 miles or so at each end of the passage, and in obedience to a standing order it was oiled every eight-bells by a quartermaster, who made due report of having done so to the officer of the watch.

† See Appendix H.

from the outer end of a small spar—a boat's mast, for instance—rigged out on the quarter. This keeps it clear of the dead-water in the ship's wake, and by a simple arrangement of out-haul and in-haul, the log need never strike the ship's side on being taken in for examination.

Mr. Frank Pett, of Dover, has patented what he terms a "Bridge Speed Communicator": in effect, it consists of an outrigger which enables the rotator to be towed alongside, whilst the "cherub" dial is on the bridge, *right under the eye of the officer of the watch.* Those who have tried it speak highly in its favour. The advantage of being able to read off the distance run without exertion is obvious. The patentee claims for it the following:—

Advantages of outrigger.

1st. The Log dial is on the Bridge under the control of the Officer of the Watch, and always handy for reference.

2nd. Saving of expense; pays for itself in two or three years in the saving of log line alone; tows log fan with one-third usual length of line. Line and Log last much longer, owing to reduced strain and friction—strain on log line, when used with the communicator, six pounds at ten knots—strain on Taffrail log, at same speed, forty pounds, a clear saving of thirty-four pounds.

3rd. No necessity to haul log in when sounding with Lord Kelvin's patent Sounding Machines, and so lose record of distance done, at the most critical time.

4th. Fan does not get foul of refuse thrown over from the ship, such as waste, rope yarns, &c.

5th. Fan and Line being always in sight from the ship's deck, any flaw can at once be detected without hauling in of log line, thus preventing the loss of many a Fan.

6th. Owing to fan not towing so far aft as the propeller, it does not get foul of latter should the ship go astern with log out.

7th. Index error remains constant at all speeds and all weathers, owing to minimum amount of strain and friction, also the log fan working in water which has not been broken up by ship's propeller.

8th. No danger of damaging fan against ship's side when taking it in.

9th. Is beyond the reach of passengers.

10th. No necessity to shift it over from the Weather to the Lee side.

11th. Simplicity of fittings. No guys or topping lift used. Can be rigged in or out in a minute.

Before stowing away a Harpoon log for a length of time, it should be immersed for half an hour or so in a bucket of fresh water, to get rid of the salt, which would otherwise dry and encrust the works, to their manifest detriment.

In certain paddle steamers, probably the best measure of speed is obtained by the revolutions of the wheels. Most of the cross-heat at a high rate of speed.† As the 'harpoon' and other similar logs are towed bodily in the water, and so get plenty of "fisherman's grease," they are not exposed to this danger. As a matter of fact, there are no patent logs yet invented which will stand the wear and tear for any length of time. In slow vessels they will of course last longer than in fast ones. Unless used only on special occasions, such racers as the *Philadelphia*, *Majestic*, or *Lucania* very quickly put them out of order.*

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In certain paddle steamers, probably the best measure of speed is obtained by the revolutions of the wheels. Most of the cross-

Speed calculated by paddle revolutions.

channel boats depend upon this method of making their runs in thick weather, and the captains of the coast boats of the Pacific Steam Navigation Co. make an invariable practice of tabulating the revolutions between their various ports of call. In vessels such as the Holyhead or Dover and Calais mail boats, where the passage is short, the vessels of great power, *and their immersion always the same,* the method is susceptible of considerable accuracy. Again, men who are going *constantly* backwards and forwards on a short run, acquire by long experience the knowledge necessary to enable them to make allowance for wind and sea, according as it may be in their favour, or against them. The slip of a screw-propeller is so variable under *apparently* the same circumstances, that in boats so driven the method is of inferior value. Experience shows that the revolutions of a paddle steamer are to be depended upon fully as much as the best patent log yet invented, with the advantage, *that the revolutions do not wear out, and the patent log does.*

ELECTRICAL LOGS.

Experiments conducted with an electrical log, made by Elliott Bros., of St. Martin's Lane, London, seem to promise well for it.

Granville's electrical log.

It provides means of indicating on the bridge, in the chart-room, or in any other desired position, the distance run, and also at any time the rate of speed per hour. Granville's log may be towed either astern or alongside as preferred; its weight is about four pounds. This is the best thing of its kind yet produced, but it has a drawback in respect of price—£18 10s.

Quite a number of similar instruments are now on the market. Among the latest is the Automatic Log Register and Log Controller of the Nautical Instrument Company, Stockholm, which appears to be both simple and satisfactory.

THE DUTCHMAN'S LOG.

This is only available for slow speeds, say a sailing vessel going anything between two and five knots. The speed is found by the time taken by a chip of wood, a cork, empty bottle, or wad of oakum to float past (on the lee side) between two marks, the distance between which is known, such as the break of the forecastle and an after-davit, or, preferably, a couple of notches cut on the rail.

The best way is to fix on some proportion of a nautical mile (6,080 feet), and the same proportion of 3,600 (the number of seconds in an hour). For instance, in a "Four-Poster," measure off 253 feet 4 inches, which is $\frac{1}{24}$th of a knot; then $\frac{3600}{24} = 150$; this number divided by the seconds taken by the chip in passing between the marks will give the hourly speed: for example, 30 seconds would give 5 knots. In practice, let the mate (standing by the after mark) get one of the youngsters to throw a chip over well ahead of the forward mark. When it comes exactly abreast, he will hold up his hand to the mate, who will note the time by seconds hand of his watch, and again when the chip floats past himself. Then reference to a little table, made on foregoing principle, will tell the speed to a nicety. It mustn't be forgotten that the Dutch were good sailors, and are still. Before Admiral Van Tromp was finally defeated, he gave the English just as much as they could manage. **Table for Dutchman's log.**

DEAD RECKONING.

Writing about logs and leads naturally leads to the subject of Dead Reckoning. Lord Kelvin, in his "Lecture on Navigation," has put the matter so clearly and forcibly, that one cannot do better than quote his words. He says:— **Lord Kelvin's remarks on Dead Reckoning.**

"When no landmarks can be seen, and when the water is too deep for soundings, if the sky is cloudy, so that neither sun nor stars can be seen, the navigator, however clear the horizon may be, has no other way of knowing where he is than the dead reckoning, and no other guide for steering than the compass.

"We often hear stories of marvellous exactness with which the dead reckoning has been verified by the result. A man has steamed or sailed across the Atlantic without having got a glimpse of sun or stars the whole way, and has made land within five miles of the place aimed at. This may be done once, and may be done again, but must not be trusted to on any one occasion as probably to be done again this time.

"Undue trust in the dead reckoning has produced more disastrous shipwrecks of seaworthy ships, I believe, than all other causes put together.

"All over the surface of the sea there are currents of unknown strength and direction. Regarding these currents, much most valuable information has been collected by our Board of Trade and Admiralty, and published by the Admiralty in its 'Atlas of Wind and Current Charts.' These charts show, in scarcely any part of the ocean, less than ten miles of surface current per twenty-four hours, and they show as much as forty or fifty miles in many places. Unless these currents are taken into account, then, the place of a ship, by dead reckoning, may be wrong by from ten to fifty miles per twenty-four hours; and the most accurate information which we yet have regarding them is, at the best, only approximate. There are, in fact, certain currents, of ten miles and upwards per day, due to wind (it may be wind in a distant part of the ocean), which the navigator cannot possibly know at the time he is affected by them.

Surface Currents.

"I believe it would be unsafe to say that, even if the steerage and the speed through the water were reckoned with absolute accuracy in the 'account,' the ship's place could in general be reasonably trusted to within fifteen or twenty miles per twenty-four hours of dead reckoning. And, besides, neither the speed through the water, nor the steerage, can be safely reckoned, without allowing a considerable margin for error.

"In the recent court-martial regarding the loss of the *Vanguard*, the speed of the *Iron Duke* was estimated by one of the witnesses at ten and a half knots, according to his mode of reckoning from revolutions of the screw and the slip of the screw through the water; while other witnesses, for reasons which they stated, estimated it at only 8·2 knots. It was stated in evidence, however, that the only experiments available for estimating the ship's speed in smooth water from the number of revolutions of the screw, had been made before she left Plymouth. If the pressure log, or even the old log-ship and glasses, had been used, there could have been no such great range of doubt. But even with the pressure log (until experimented upon, as it probably will not be except by the Navy, because not needed for thorough practical work except by the Navy), we could scarcely tell with certainty within a quarter of a knot what the actual speed of the ship through the water is at any instant. And, again, the Massey log may be held to have done its work fairly well if it gives the whole distance run by the ship in any interval within five per cent. of the truth.

Speed errors.

"Consider further the steerage. In a wooden ship a good ordinary compass, with proper precautions to keep iron from its neighbourhood, may be safely trusted to within a half quarter point; but, reckoning the errors of even very careful steering by compass, we cannot trust to making a course which will be *certainly* within a quarter of a point of that desired. Now you know an error of a quarter of a point in your course would put

Compass errors

you wrong by one mile to right or left of your desired course for every twenty miles of distance run. Thus, in the most favourable circumstances, you are liable, through mere error of steerage by compass, to be ten miles out of your course in a run of only two hundred. Steering errors

"In an iron ship, if the compass has been thoroughly well attended to as long as the weather permitted sights of sun or stars, a very careful navigator may be sure of his course by it, within a quarter of a point, when cloudy weather comes on; but by the time he has run three or four hundred miles, he can no longer reckon on the same degree of accuracy in his interpretation of its indications, and may be uncertain as to his course to an extent of half a point or more until he again gets an azimuth of sun or star.

"No doubt an exceedingly skilful navigator may entirely, or almost entirely, overcome this last source of uncertainty when he runs over the same course month after month, and year after year, in the same ship; but it is not overcome by any skill hitherto applied to the compass at sea when a first voyage to a fresh destination, whether in a new ship or an old one, is attempted.

"All things considered, a thoroughly skilled and careful navigator may reckon that, in the most favourable circumstances, he has a fair chance of being within five miles of his estimated place after a two hundred miles' run on dead reckoning; but with all his skill and with all his care, he may be twenty miles off it; and he will no more think of imperilling his ship and the lives committed to his charge on such an estimate, than a skilled rifle-shot would think of staking a human life on his hitting a bull's-eye at five hundred yards. Possibilities of D. R.

"What, then, do practical navigators do in approaching land after a few days' run on dead reckoning? Too many, *through bad logic and imperfect scientific intelligence, rather than through conscious negligence,* run on, trusting to their dead reckoning. In the course of eight or ten or fifteen years of navigation on this principle, a captain of a mail steamer has made land just at the desired place a dozen times, after runs of strictly dead reckoning of from three or four hours to two or three days. Perhaps of all these times there has only once been a strictly dead reckoning of over thirty hours with satisfactory result. Still, the man remembers a time or two when he has hit the mark marvellously well by absolutely dead reckoning; he actually forgets his own prudence on many of the occasions when he has corrected his dead reckoning by the lead, and imagines that he has been served by the dead reckoning with a degree of accuracy with which it is impossible, in the nature of things, it can serve any man. Meantime, he has earned the character of being a most skilful navigator, and has been unremitting in every part of his duty, according to the very best of his intelligence and knowledge. He has, moreover, found favour with his owners, through making excellent passages in all weathers, rough or smooth, bright or cloudy, clear or foggy. At last the fatal time comes, he has trusted to his dead reckoning once too often, he has made a 'centre,' not a 'bull's-eye,' and his ship is on the rocks."

Every seaman of experience will admit the perfect justice of these remarks, even were they not corroborated by the revelations of the Inquiry Courts.

Captain John Miller on Dead Reckoning.

A very valuable paper on the subject of dead reckoning has been written by the late Captain John Miller, and will be found in the *Mercantile Marine Service Association Reporter*, Vol. III., page 415. It is also given in the May number of the *Nautical Magazine* for 1878. The reader would do well to refer to it.

Do not forget to look to your log-*glass* as well as your log-*line*, especially when nearing land. Test it by the chronometer.

Permanent deck marks for measuring log and lead lines.

For convenience of testing the length of the log and leadlines, the required distance should be permanently marked (with copper tacks) on the quarter-deck; 23 ft. 4 ins.—the length of a knot corresponding to a glass running 14s.—being laid off on the port side, and single fathoms up to five, on the starboard side. It is always best to have the leadlines fitted with *calico* for white marks, *bunting* for red marks, and *serge* for blue marks, because in the dark a man can tell the difference by the feel. Test the measurements of the lines immediately after use, *when they are wet and well stretched.*

The following is from the able pen of the late Mr. Thomas Gray, C.B., to whom sailors of all nations owe a lasting debt for his popular exposition of the Rule of the Road at sea:—

L. L. L. L.

THE MARINER'S CREED.

TO BE SAID DAILY, AND ACTED ON ALWAYS.

I understand L. L. L. L. to be the symbol or sign for four things which I must never neglect; and these things are: Lead, Log, Latitude, and Look-out.

Therefore, I say, use the Lead and the Log; and mind the Latitude and the Look-out.

I believe in the Lead, as it warns me against dangers which the eye cannot see.

I believe in the Log, as it checks my distance run.

I believe in ascertaining the Latitude, as it helps to define my position.

I believe in the Look-out, as it warns me against dangers to be seen.

The Lead warns me against dangers invisible, the Log warns me against false distances, the Latitude helps to define my position, and the Look-out warns me against dangers visible.

And I earnestly resolve, and openly declare, that as I hope to sail my ship in safety on the ocean, as I wish to spare the lives of my fellow-creatures at sea, and as I wish to go in safety all my days, so will I steadfastly practise that which I believe.

And I hereby warn seamen, and tell them that if they neglect any one of these four things, either the Lead, the Log, the Latitude, or the Look-out, they or their fellows will some day surely perish."

Before leaving the subject of sea-sounding, it will be interesting to mention the maximum depth yet discovered in the Mediterranean. In 35° 45′ N., 21° 46′ E. (about 50 miles south-west from Cape Matapan), the Austrian surveying vessel *Pola* found a depth of 2,408 fathoms, followed, within a few miles further east, by a depth of 2,231 fathoms. This area has received from the Austrian Hydrographical Board the name of 'Pola Deep.' **The *Pola's* discoveries.**

The temperature at the first named depth was 56°; but the lowest (52½°) was observed at the exit from the Adriatic, at the moderate depth of 415 fathoms.

The density of the water in the eastern Mediterranean is greater than in the western Mediterranean, and varies but very little at any depth from 1·030. The transparency also is very great. In three cases a white disc was seen down to a depth of 29½ fathoms, but in the 'Pola Deep' it disappeared at 17½ fathoms.

CHAPTER XIII.

THE MARINE BINOCULAR AND TELESCOPE.

In a work of this character it would be undesirable, even if practicable, to enter seriously on all the complex properties of telescope lenses, and the difficulties—optical and mechanical—attending the various stages of their manufacture. But whilst avoiding the abstruse questions which might possibly get the writer out of his depth, it will be of interest to the reader to have explained in a general way the elementary principles upon which the action of a telescope depends. Thus posted, a purchaser will have a better notion of what he is about, and will be able personally to select instruments suitable to what may be his special requirements, for it will be made manifest that those adapted for one purpose—however good in themselves—are not necessarily so for another.

Points to be discussed.

To begin at the beginning, it is desirable to say just a few words about *some* of the properties of light.

Properties of light.

1. Light is the agent which, by its action on the retina of the eye, excites in us the sensation of *vision*.*

2. A *medium* is any space or substance which light can traverse, such as a vacuum, air, water, glass, &c. A medium is said to be *homogeneous* when its composition and density are the same throughout. A coal-laden ship would ordinarily be considered to have a homogeneous cargo, though it might not, and probably would not, be so in fact. For example, part might be from one mine and part from another, yielding coal of very different densities.

3. In every homogeneous medium, light is propagated in a straight line.

4. Light changes its direction on meeting an object which it

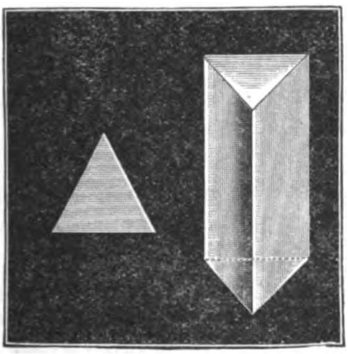
* The retina is the delicate membrane by which the back part of the globe of the eye is lined, and in which the fibres of the optic nerve terminate. It is the function of the optic nerve to transmit visual impressions to the brain, which is the seat of all our sensations.

cannot penetrate; also when it passes from one medium to another. The first process is termed *reflection*, and the latter *refraction*.

A seaman having only to deal with *refracting* or *dioptric* telescopes, we will confine ourselves to the phenomenon of *single refraction*.

Refraction is the bending which occurs in rays of light when passing *obliquely* from one medium to another; water and air afford the most common illustration of this, witness the bent appearance of an oar-blade as seen in clear water. The word *oblique* is italicised because, should the incident ray be *perpendicular* to the surface separating the two media, it is not bent in the least, but continues on in the same straight line as before.* Reference to nautical tables will shew that refraction is greatest at the horizon (33′ 46″ with barom. at 30 inches and air at 50°), where light enters our atmosphere most obliquely, and vanishes altogether at the zenith, where it enters *perpendicular* to our atmosphere. *See page 91.* **Refraction**

Everyone knows what a triangular prism of glass is. They are commonly used as ornaments for chandeliers, &c., and are then spoken of as 'drops.' Subjoined are two views of a prism; the first shews it 'end on,' and the other as it would appear if looked down upon obliquely.



A prism.

Most people know also that the various glasses in a telescope are termed *lenses*. In section they are of several different forms, and always more or less prismatic. Sometimes two, or perhaps three, are closely united by some substance, such as Canada **Lenses.**

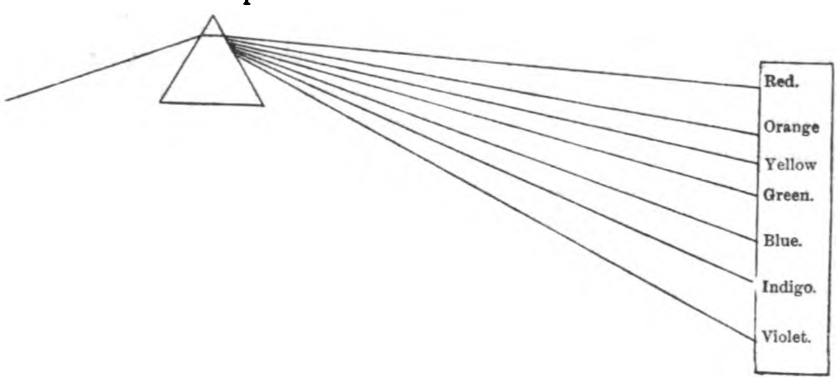
* *Perpendicular* is merely another expression for "at right angles," and must not be confounded with *vertical*.

balsam, which is transparent, and has a refractive power nearly equal to glass: they are then termed *compound* lenses.

When ordinary white light passes through a simple lens, which may be compared to a series of prisms with infinitely small faces like microscopic steps of stairs, it is not only *refracted*, but is partially *decomposed* or separated into its constituent colours, the

Dispersion.

different coloured rays coming to a focus at different distances, owing to their varying degrees of refrangibility. The focus for red rays, which are the least refrangible, is obviously furthest from the lens; and that for violet rays is nearest to it, the foci of the orange, yellow, green, blue, and indigo lie between in the order shewn in the subjoined spectrum. The diagram does not shew the focal points.



This peculiar *dispersive* effect is observed in the rainbow, which is an arch formed opposite to the sun by the refraction *and* reflection of the sun's rays in drops of falling rain. Thus we have

Chromatic aberration.

the *chromatic aberration* of a lens arising, as shewn, from the different refrangibilities of the coloured rays into which white light is split up in its passage through a prism. Owing to the different focal lengths of the rays, chromatic aberration causes overlapping images with a fringe of colour, and consequent indistinctness or want of sharpness at the edges.

But this is not all. Even supposing the light to be of a single or uniform degree of refrangibility, the spherical surfaces of the lens would introduce another element of trouble, inasmuch as the rays, which enter near the margin of the lens, will come to a focus sooner than those which enter near the axis or centre.

Spherical aberration.

This is called *spherical aberration* or *confusion*, and in the case of the *simple* lens can only be cured without losing light—and then but partially—by making its radius of curvature excessively large, or, in other words, by giving it an enormously long focal length, which of course would be impossible with portable telescopes.

But of the two defects, the first named is much the more serious, and no way of avoiding it was known until the middle of the eighteenth century. The fact had, indeed, been recognized by mathematicians and physicists that every transparent medium has a special *quality* of refraction, and, consequently, that if two kinds of glass could be produced having very different ratios of *refractive* to *despersive* powers, the defect could be cured by combining lenses made of these different kinds of glass, and thus enable white light to be refracted to a focus without being dispersed or broken up into its coloured components. **Combination of lenses.**

This idea, however, was not realised in practice until the time of the celebrated optician, John Dollond, who, about the year 1757, demonstrated that a satisfactory objective could be made by combining a concave lens of flint glass with a double convex lens of crown glass, in such manner that the *dispersive* powers of the two lenses should neutralise each other, being equal and acting in opposite directions, whilst the crown glass, having its *refractive* power increased by giving to it additional curvature, would cause the emergent rays to converge to the required focus for magnification by the eye-piece.

Crown is a comparatively light glass made of sand, sulphate of soda, and lime; whilst *flint*, containing sand, carbonate of potash, and red-lead, has nearly double the density: hence their different refractive powers. **Composition of glass.**

As now made, the outer or crown glass lens of the objective is double-convex, whilst the inner or flint one is generally nearly plano-concave. The adjoining surfaces are worked to such a nicety that they fit together almost as one. It would not do for any but an optician to take the glasses apart, as they are ground for a given relative position, and would not be true for any other.

In all cases, however, the true convergence of the white ray is only obtained by a modification in the shape of the spherical surfaces. In the trade this elaborate process is termed 'figuring,' and has generally for its object an alteration of form in the direction of an elliptical section. It requires on the part of the operator such skill, patience, and care as few possess. **'Figuring.'**

To ensure to the image perfect definition and sharpness, it is absolutely necessary to have

1. The right quality of material.
2. Freedom from blemish in the material.
3. High-class and specially gifted workmen.

4. Talented supervision.

Castings for object-glasses.

To obtain castings of large size free from veins, and homogeneous throughout, is a matter of *extreme* difficulty. Failures are many. All this means time, patience, and *money*, so it is no wonder that big refracting telescopes can only be produced at great expense. Hurry is out of the question.

So far, the reference has been more particularly to the object glass, or *objective* as it is termed, but this in itself would be worthless without the eye-piece or *ocular*. It would be like a violin without strings.

The eye-piece.

To all intents and purposes the ocular is neither more nor less than a microscope, its duty being to magnify the image which has been brought to a focus for this purpose by the objective. Each, then, has its own special work to do: one is a collector of the light emanating from the object, and the other a magnifier of its image. The eye-piece is a combination of lenses varying according to the purpose for which the telescope is intended. One form—*the diagonal eye-piece*—may at once be dismissed, as the general run of seamen have no concern with it.

The *astronomical eye-piece*, which is the simplest form, shews the object upside down; on this account it is often termed the '*inverting eye-piece*.' This, however, is not right, as it is really the object glass which is responsible for the inversion. The eye-piece in this case merely takes the image as it finds it, and, after magnification, passes it on to the observer without rectifying the position. It has but two lenses, of the kind known as plano-convex. The convexities are towards each other, and their distance apart is regulated by a rule which need not be stated.

Versatility of genius.

This particular form of eye-piece takes its name from Jesse Ramsden, a son-in-law of Dollond, who, beginning life as a cloth-worker, subsequently achieved great eminence as a mathematical instrument maker. Dollond himself began as a silk-weaver.

The Ramsden eye-piece is not suitable for a ship's telescope, which is intended to shew things in their natural position. To secure this we must have recourse to the '*erecting*' eye-piece. It has four lenses, and only accomplishes its purpose by sacrificing a certain amount of light, due to the fact that each lens charges a toll for transmission: that is to say, there is a percentage of loss at each of the four lenses, or we may put it that the transparency of glass, however pure and good, is not absolute. Therefore, for equally distinct vision to that obtained with the Ramsden eye-piece. the telescope fitted with an erecting one must have a larger object glass. Rather than sacrifice light, astronomers invariably use inverting telescopes, and if seamen could but educate themselves up to it, there is no doubt that they would be an advantage in their case also. It is significant that those who accustom themselves to the inverting telescope of the sextant never go back to the other, though it must be admitted that the cases are not altogether similar; a round object like the sun appears the same whichever side is uppermost.

Definition. Of course it will be understood that the lenses of an eye-piece are subject to the same troubles as those described in connection with the object-glass, and are cured in much the same manner. But there is also another dodge, not yet alluded to, which assists in the cure. *Spherical aberration*, more especially, is prejudicial to good definition, so at various points in the interior of the tube are placed thin discs of metal with a central aperture, the size of which is regulated according to circumstances. These rings are termed 'stops,' and their business is to intercept the extreme rays near the edge of the lens, also to cut off any extraneous light which may enter the telescope slantingly, and which, if not intercepted, would produce a fogginess over the whole field of view. **Fogginess.** In this latter duty the 'stops' are aided by an external tube, capable of being extended for several inches beyond the object-glass. This is appropriately named a 'ray-shade.' Should the telescope be pointed so much in the sun's direction that his rays would enter it, the effect would be to cause internal reflections; to diminish these the interior of the tube is coated a dead black, and the ray-shade is of course drawn out to its full length.

In connection with this matter of 'stops,' should the object-glass be indifferent, it is just possible the maker—rather than reject it—may seek to conceal its shortcomings by unduly reducing the aperture of the 'stop,' so as only to permit of the central portion of the lens being brought into use. **Effective diameter of objective.** For example, let an objective of two inches diameter be 'stopped' to such an extent as to reduce its effective diameter to 1·4 inches. In this case the buyer will be paying for just *half* of what he thinks he is getting. Imposition of this kind can easily be detected as follows:—Focus the telescope as usual, then look through it *from the big end*, and if, by moving the eye to one side, the circular aperture should be interfered with, make a corresponding mark on the glass. Repeat this on the other side. The distance between the two marks is the *effective* diameter of the object-glass. It is usual in all but the very best glasses to allow a *small* amount of 'stop,' but if

Land-sharks. excessive, the telescope should be rejected as a rank pretender. Therefore, Brother, keep your weather eye lifting, or you may be sold along with the telescope.

The main features in the *construction* of the telescope having now been disposed of, we may proceed to other considerations, and will commence with a very popular error, namely, that distant objects are seen more distinctly in proportion to the magnifying power employed. If this were really so, it would be better to use a small microscope, magnifying, say 300 times, than the bulkier ship's telescope magnifying but 30 times. It is not merely by *magnifying* that the telescope assists vision; but also, and more especially, by *increasing the quantity of light*, which comes to the eye *from the object under inspection.* For example, should we view an object through an instrument which magnified but did not increase the light received by the eye, it is evident that its brilliancy would be lessened in proportion as the surface of the image was enlarged, since a *constant* or *fixed* amount of light would be spread over an *increased* surface; and thus, unless the light in the first place happened to be particularly strong, the object might actually become so darkened by the use of a high power as to be less plainly seen than with the naked eye.* It is for this reason that the eyes are unduly strained in the endeavour to make out the details of an object, as seen through some ill-constructed telescopes of high magnifying power and small aperture.

Subordination of parts.

Under such conditions flags fluttering in the wind are especially difficult to make out, the colours appearing much less vivid than they should do; in fact, they look washed out.

How the telescope increases the quantity of light will be apparent by considering that, when the unaided eye looks at any object, the retina can only receive as many rays as fall upon the pupil.† Now, by the use of the telescope, *as many rays can be concentrated and brought to the retina as fall on the entire object-glass.* No wonder, then, that to look at the sun through a telescope of any size without the intervention of a very dark glass, means instant destruction to the sight.

* If the image be as much larger than the object as the object-glass is larger than the pupil of the eye, the object and its telescopic image will appear equally bright. Practically, as will presently be seen, the most formidable difficulty in attaining very high magnifying powers, is that due to the enormous sizes of the object-glasses which are required to impart the necessary brightness to the enlarged image.

† The small contractile aperture in the centre of the eye.

The pupil and the retina. The pupil of the human eye in its normal state has a diameter of $\frac{1}{5}$th of an inch, and by the use of the telescope the retina is virtually increased in surface in the ratio of the square of the diameter of the object-glass to the square of $\frac{1}{5}$th of an inch: thus, with the 2-inch aperture of the ordinary ship's telescope, the number of rays collected is just one hundred times as great as the number collected with the naked eye. For example, the number of fifths of an inch in the diameter of a 2-inch objective is of course 10, and 10 multiplied by itself is 100.

The power of the telescope To go a little further in this direction. If the brightness of a star seen with the eye alone be put at 1, then with a 2-inch telescope it becomes 100 times as bright; and with a 4-inch telescope it is 400 times as bright, because the square of 2-inch being 4, and the square of 4-inch being 16, the brilliancy is as 16 to 4, or four times as great.

Size, how described. It must be understood that the size of a telescope is described by the diameter of the object-glass, and *not* by the length of its tube, as many might suppose.

Following the rule as above, we find that the brightness of a 10-inch telescope is twenty-five times more than that of a 2-inch. Thus the square of 2-inch is 4, and the square of 10-inch is 100; 4 into 100 will go 25 times. In this way it will be seen that "big *Jim*," of the Lick Observatory, with an objective 36 inches in diameter, receives 324 times more light than a ship's telescope, or 32,400 times more than the unaided human eye.

Now, it is evident that for use on board ship there is a limit to the size of a telescope. This limit may be fixed at 2¾ inches, which, with a pancratic eye-piece, permits of magnifying powers of 50, 60, and 70. The last would of course only be used in very clear, bright weather, *and smoothish water*. It has already been pointed out that, for the same sized object-glass, the higher the power the fainter the picture; but, in addition, there is the further drawback that *the field of view is narrowed*. This latter is a very serious matter indeed, as it increases the difficulty (always experienced afloat) of keeping the instrument fixed on the object under scrutiny, the least motion at once putting it out of the field, so that a continuous and steady look is impossible. Can anything be more annoying? In misty weather, also, a glass with great magnifying power is unsuitable, as it magnifies the haze as well as the object, and of course renders the latter even more blurred and indistinct than before.

Power and field.

Hence the advantage of the pancratic eye-piece with varying powers, which can be used according to circumstances. A $2\frac{3}{4}$-inch pancratic telescope when pulled out measures about 4 ft. 9 in. With the ordinary eye-piece, and a power of 30, a $2\frac{3}{4}$-inch when open would measure about 3 ft. 7 in. The difference in the price is very little. A $2\frac{3}{4}$-inch will show stars of 11th mag.

Weather regulates power.

The writer possesses an elegant $2\frac{1}{8}$-in. pancratic telescope by a well-known London maker, which magnifies 30, 40, or 50 times. It has two 'draws.' For general purposes the one nearest the observer is not pulled out or touched in any way, and the glass then magnifies but 30 times, which is mostly good enough; if, however, an exceedingly bright clear day justifies the use of a higher power, it can be obtained up to 50 by drawing out the small or pancratic tube, which is marked by numbered rings, so as to indicate the precise power employed: the focussing is done with the other tube as before. The open length of this glass is 3 ft. 6 ins.

Calcutta pilots, who have often to look for small channel marks when yet a long way from them, invariably bring on board their own telescopes, and but seldom accept the proffered binocular. It must be remembered, however, that the use of these powerful instruments is, in their case, restricted to clear sunshiny weather and perfectly smooth water.

Atmospheric undulations.

A great enemy to the use of the telescope is the unsteadiness of the air itself. We view objects through an atmospheric medium which is never at rest, and its undulations—which sometimes even the naked eye can detect—are magnified in proportion to the power employed. The circumstances, therefore, under which high powers are applied are often such as to render the object much less distinct than the mere value of the magnifying power in use might seem to warrant.

It is now time that we gave the Binocular a turn.

The Binocular.

In principle it is precisely the same as the telescope, of which it is the simplest form. It consists merely of two lenses in each barrel, namely, a double convex objective and a diverging or double concave ocular. It gives an erect image. Having only two lenses, it absorbs very little light, and as each eye has its own telescope, still greater brightness is obtained. All this points to the special qualification of the binocular for night work. Another point not without its advantage is that the focussing does not require such very fine and careful adjustment as in the case of the telescope, where the manipulation—especially with large magnifying powers—has to be very delicately done. With the binocular, on the contrary, the lengthening or shortening of the instrument does not produce so decided an effect on the divergence of the light, and the accommodating power of the eye is accordingly able to make up for any small error in the focussing. The use of both eyes, moreover, permits of seeing things standing out stereoscopically as in natural vision.

Marine binoculars differ, or should do, from the instruments in use on shore. Such fancy articles as those fitted with revolving eye-pieces, which, according to the particular one employed, constitute them either Marine, Field, or Opera glasses, are quite unsuitable for use on board ship. Fancy articles.

Binoculars, when first introduced for sea use, were intended exclusively as night-glasses, but, from their extreme portability and large field of view, were soon found to be so convenient for general service, that, before long, opticians manufactured them of patterns to meet nearly all requirements. The binocular is now so universally popular that she must indeed be a lowly type of craft that does not possess one or more among the after-guards. Their manufacture is confined almost exclusively to Paris.

In the binocular, as well as the telescope, high magnifying power and the acquisition of light are invariably opposed to each other, and it is always necessary that one of these qualities should be more or less subordinate to the other, according to the particular purpose for which the instrument is intended. Consequently, in the Night-glass, where the main desideratum is to collect as much light as possible, to enable that which is looked at to be seen with distinctness, it is evident that we cannot expect much magnifying power.

On a dark night, when sweeping the horizon in quest of ships, land, or buoys, it is obvious that the greater the area embraced, the greater the likelihood of picking up the object sought for.

The object glasses of the binocular should therefore be as large as possible, consistent with a requirement hereinafter to be named; and of short focal length, by which combination you not only gain *good illuminating power*, but also the important advantage of a *wide field of view*. Object lens what kind most suitable

From these considerations it will be evident that the proper way to select a binocular for *night* use is, *not* to stand at a shop door in broad daylight, trying how much it *enlarges* some distant clock-face, but to wait until nightfall, and test it by looking up a dark street or passage; and if figures, before only dimly visible to the naked eye, are rendered tolerably clear by the aid of the How to select binocular for night use.

glasses, you may rest assured you have hit on a suitable instrument.

The principle aim, therefore, of the night-glasses (as already stated) being to intensify and get as much light and field as possible, you must be prepared to sacrifice magnifying power, which should never exceed four diameters.

How to determine magnifying power.

A simple method of determining this latter quality is to look at any suitable object with one eye unaided, whilst with the other we use one tube of the binocular. The object will then be seen in its natural size, and at the same time as magnified by the instrument. By a little manipulation the two images can be brought side by side, or made to overlap, when it will be easy to see how many times the magnified image is larger than the natural one.

Width between glasses to correspond with width between eyes.

Another point essential to be remembered—and this it is which unavoidably limits the size of the object glass—is, *that the centre of curvature of the lenses should be exactly opposite the pupil of each eye; or, in other words, that the distance between the right and left-hand glasses should correspond to the distance between the eyes—centre to centre.* This is capable of easy measurement; so, in choosing your binoculars, those not corresponding to this requirement should be at once rejected, irrespective of other considerations. It is seldom that the distance between the pupils permits of a larger object glass than 2⅜-inches diameter, as it will be apparent to anyone that its measure must be a *little* less than the aforesaid distance, to allow for setting in the frames. Hence a good and well made pair of glasses may suit one man perfectly, and another not at all.

Hinged binoculars.

A binocular has been devised, fitted with a hinged joint connecting the twin parts, so that the distance between the barrels can be increased or diminished at pleasure, to suit different eyes, but for several reasons it is not a success.

The best achromatic binoculars have six lenses in each tube, three being combined to form the object glass, and three to form the eye-piece. Such a combination is termed a 'triplet.' Medium-priced binoculars have an achromatic object glass of two lenses, and a single eye lens; but in the very common glasses, both the objective and ocular are of the simple form, and the fringe of colour, inseparable from their use, fatigues the sight and impairs the sharp definition of whatever is looked at.

Without being in the least afflicted with colour blindness, it is difficult, when using cheap glasses on a dirty night, to distinguish with certainty the colour of a vessel's lights, especially when the latter happen to be nothing extra in themselves. Under such unpleasant circumstances a white light is apt to have a greenish or reddish tinge, as the case may be; or a green light, as likely as not, is mistaken for a white one. It is important, therefore, to be provided with the best article if you wish to guard against collisions.

The common long-draw binocular is always to be avoided, as with wear the sliding tubes work slack, and the parallelism of their axes being destroyed, the observer "sees double." This remark does not apply to a binocular of superior make now coming much into favour with yachtsmen and tourists. It is to all intents and purposes a small double-barrelled *telescope*, a condition inconsistent with its use as a *night-glass*. For day use, however, these glasses are admirable as a substitute for the telescope, and being easier to hold, recommend themselves greatly to ladies, or to gentlemen who have not got their sea-legs aboard. The high price of the good ones—£10 to £20—restricts their sale, and, after all, they are nothing more than a compromise. **Tourists' binoculars**

To protect the eyes from a strong cold wind, it is a good plan to have the binoculars furnished with a concave shield of thin brass, made to fit closely to the face, and to ship and unship when required. Any handy engineer on board can do this, and it will be found a great comfort to persons with weak eyes. **Eye shields.**

Many men, from its greater portability, habitually use the binocular in the day time; but where the distance is great, and the object small, it has to give way to the more powerful telescope.

Now that it can be obtained cheaply, the best metal for binocular or telescope is undoubtedly aluminium. In strength and toughness it rivals steel; in non-liability to corrosion it is almost as good as gold; and in lightness it stands altogether alone, being only one-third the weight of copper or brass.

In providing yourself with these instruments, recollect that each has its own important, but perfectly distinct, function. Of all things, beware of "Cheap Johns." If you wish for a *really* good article, you must be prepared to pay a reasonable price for it.*

* Some years ago the author's curiosity was excited by the seemingly marvellous statement in the window of a shop, in a certain town, both of which shall be nameless, that a binocular, exhibited for sale, had rendered an "object" visible at the distance of ninety miles. This was attested by a letter to be seen within. On enquiry, the "object" turned out to be none other than the island of Tristan d'Acunha, which, as most southern-going sailors know, is sometimes visible to *the naked eye* at even a greater distance. This reminds one of the anecdote of the Cockney tourist on the summit of Ben Lomond: on remarking to his Scotch guide that they could discern objects at a great distance, the **Gullibility of sailors taken for granted.**

guide replied that if the other would only just wait a couple of hours or so, he would be able to see something much further still. Guess the feelings of the tourist when, on enquiring what he would see, he got for answer, "*you'll see the moon.*" Not long since another shop notice caught the author's eye; it was to the effect that the binocular it referred to would enable a person to be recognised at a distance of five miles. Now, when it is known that at that distance a man of average height will only subtend an angle of forty-five seconds (three-quarters of a minute of arc), it will at once be evident that such a statement is ridiculous.

For some years there has been quite a craze for big telescopes, nor is it to be wondered at. Lord Rosse's famous reflector was the first of the giants, and dates back to 1845. Including mounting, &c., it cost £30,000. It has a metal speculum or mirror of 4 tons in weight and 6 feet in diameter. Its *light-gathering* power is consequently enormous, but, owing to defects in curvature, its *defining* power is surpassed by the much more perfect instruments of recent construction, such as that belonging to Mr. Ainslie Common, the astronomer of Ealing, which has a silvered glass mirror of 60 inches in diameter. This magnificent telescope, though smaller than Lord Rosse's, is considered by many to be the most powerful one in existence.

The principal observatories of the world are rapidly getting equipped with refracting telescopes of extraordinary size. Washington has one of 26 inches; Vienna, 27 inches; Greenwich, 28 inches; Pulkowa, 30 inches; but, as usual, the Americans out-distance every other nation. On one of the summits of Mount Hamilton (California), at an elevation of 4,227 feet above sea level, and in an atmosphere which, astronomically speaking, is perfect, an observatory has been erected, containing a refractor with which excellent work has been done. The observatory and its appointments are the gift of Mr. James Lick, an American millionaire, who left to the University of California 700,000 dols. for the purpose. In 1885, after trials extending over six years, during which there were 19 failures, the glass discs for the objective were successfully cast by Feil, of Paris; these were worked to a true figure, polished, and finished in 1886 by Alvan Clark, of Cambridge, near Boston, U.S.A. The objective is 36 inches in diameter, and cost £10,000. The tube, which is 57 feet long, weighs 4½ tons, has a diameter of 4 feet in the middle, and cost about the same as the lenses. The iron pier supporting the telescope and its mechanism stands about 30 feet high, and weighs 25 tons. This pier rests upon a massive stone foundation, in which is a tomb enclosing the remains of the donor, deposited there with some ceremony on January 9th, 1887. The maximum magnifying power of the Lick telescope is 3,360, and with it, at midnight of September 9th, 1892, was discovered the 5th satellite of Jupiter. There would appear to be no finality in man's ambition, for the late Mr. Charles Yerkes—another wealthy American—"donated" 500,000 dols. to the University of Chicago to construct a still bigger refractor. The objective is 40 inches in diameter, and is nearly a third more power than the 'Lick'; but, in point of atmospheric conditions, the site chosen is stated to be not nearly so good.

Refracting telescopes were invented first, but in both kinds the fundamental principle is the same. The large lens or mirror—as the case may be—forms at its focus a *real image* of the object looked at, and this image is then examined and enlarged by the eye-piece, whose function it is to act the part of a powerful magnifying glass.

CHAPTER XIV.

LORD KELVIN'S NAVIGATIONAL INSTRUMENTS.

1. NEW FORM OF AZIMUTH AND STEERING COMPASS, WITH ADJUNCTS FOR THE COMPLETE APPLICATION OF THE LATE ASTRONOMER-ROYAL'S PRINCIPLES OF CORRECTION FOR IRON SHIPS.

The founder of present system

In 1838, the attention of the late Sir George B. Airy, then Astronomer-Royal, was occupied by important experiments with the object of analysing the disturbance produced in the compass needles of iron ships. These experiments were carried on for the most part in H.M.S. *Rainbow*, in Deptford Dockyard. They bore good fruit, for in two papers presented to the Royal Society, the first in 1839, and the second in 1855, Sir George shewed how the errors of the compass may be perfectly corrected by permanent magnets and soft iron placed in the neighbourhood of the binnacle. Partial applications of his method came immediately into use in merchant steamers; and within the last twenty-five years have become universal, not only in the merchant service, but in the navies of England and other countries.

Here it may be said that, although improvements in the method of correction have been made, the general principle is still the same.

Lord Kelvin's experiments.

Some twenty odd years ago the attention of Lord Kelvin was forced to this subject, through his having been called upon by the Royal Society to write a biographical sketch of the late Mr. Archibald Smith, with an account of his scientific work on the mariner's compass and ship's navigation; and he therefore commenced to make trial compasses with very much smaller needles than any previously in use; but it was only after three years of very varied trials in the laboratory and workshop, and at sea, that he succeeded in producing a mariner's compass with the qualities necessary for thoroughly satisfactory working in all weathers and all seas, and in every class of ships, and yet with guide replied that if the other would only just wait a couple of hours or so, he would be able to see something much further still. Guess the feelings of the tourist when, on enquiring what he would see, he got for answer, "*you'll see the moon.*" Not long since another shop notice caught the author's eye; it was to the effect that the binocular it referred to would enable a person to be recognised at a distance of five miles. Now, when it is known that at that distance a man of average height will only subtend an angle of forty-five seconds (three-quarters of a minute of arc), it will at once be evident that such a statement is ridiculous.

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Theoretically speaking, a compass-card constructed on true scientific principles, properly compensated for the ship's magnetism, and mounted in the right sort of bowl, *is a stationary object in space:* that is to say, no matter how frisky the ship may be, or whether the circle be made under port helm or starboard helm, the needles should unswervingly point straight to the magnetic north. In other words, it is a desirability that, under all circumstances, the compass-card should remain perfectly stationary, and the nearer this condition is approached the better the compass.

Friction must be minimised.

On account of friction on the pivot—if for no other reason—this result could not be even approximately achieved with the heavy cards, before Lord Kelvin set his wits to work to solve the problem. The old-fashioned cards, when experimented upon, would not—when deflected—return to rest in the magnetic meridian as they invariably ought to do; nor even could they be depended upon to settle down again at the point from which they started, whatever that might have been. This was due to the fact that the relation of the needles in point of magnetic power to their own weight, added to that of the card and its framework, was not such as would fully control the card. It is therefore one of the qualifications of a good compass that the needles must be able to overcome the friction on the pivot, or the essential feature of the instrument is sacrificed.

Weight of card.

It is an obvious thing in mechanics that if you have a heavy weight you have a heavy friction, and if you diminish the weight you diminish the co-efficient of friction. Lord Kelvin's card weighs only half-a-crown (2s. 6d.) or $\frac{5}{8}$ of an ounce, whereas the Admiralty Standard Compass Cards "A" and "J" weigh respectively $3\frac{1}{2}$ ounces and $6\frac{3}{4}$ ounces—a vast difference, shewing, moreover, by results, that the Admiralty system was fundamentally wrong.

Reason for a number of needles.

Among other devices for securing the maximum of directive force for any given weight, Lord Kelvin, taking advantage of the fact that magnetism resides principally, if not wholly, in the surface, uses a plurality of needles whereby greater surface is secured than would be the case were the same amount of material used in a lesser number of needles of the same length.

Another result at which Lord Kelvin arrived, partly by lengthened trials at sea in his own yacht, and partly by dynamical theory analogous to that of Froude with reference to the rolling of ships, was that steadiness of the compass at sea was to be obtained *not* by heaviness of needles or of compass card, or of added weights, but by longness of vibrational period* of the compass, whatever way the longness may be obtained. Thus if the addition of weight to the compass card improves it in respect to steadiness at sea, it is not because of the additional friction on the bearing point that this improvement is obtained; on the contrary, the dulness of the bearing point, or too much weight upon it, renders the compass less steady at sea, and, at the same time, less decided in shewing changes of the ship's head, than it would be were the point perfectly fine and frictionless, supposing for a moment this to be possible.

Vibrational period.

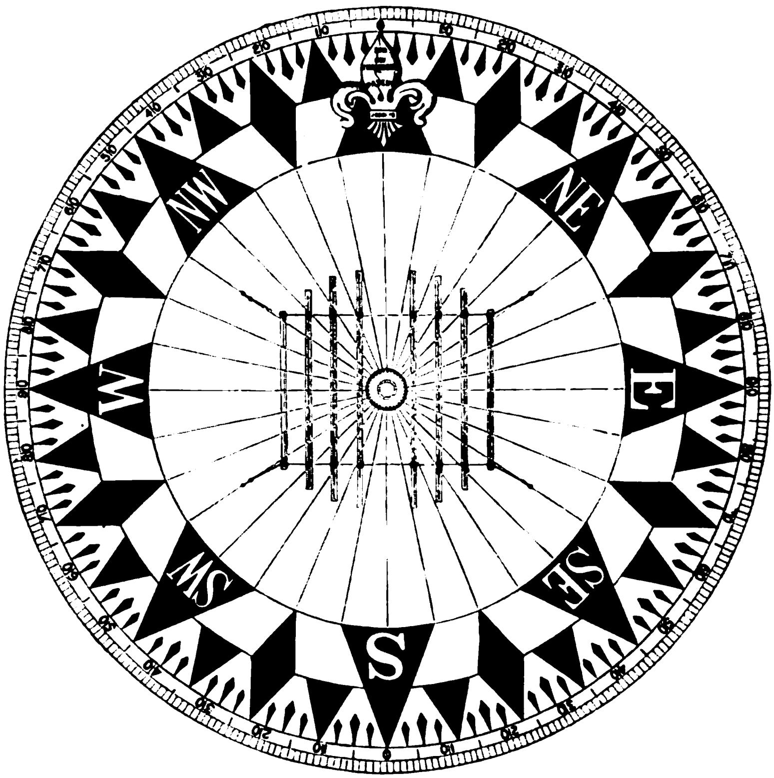
It is by increasing the vibrational period that the addition of weight gives steadiness to the compass; while, on the other hand, the increase of friction on the bearing point is both injurious in respect to steadiness, and detrimental in blunting it or boring into the cap, and so producing sluggishness after a short time of use at sea. If weight were to be added to produce steadiness, the place to add it would be at the very *circumference* of the card, by which means it would acquire a large moment of inertia, depending upon the extended radius of gyration. This would give a longer period compared with that which we have with a shorter radius of gyration and the same magnetic influence.†

Weight of card to be carried at outer edge

The conclusion that Lord Kelvin came to was that no weight is in any case to be added, beyond that which is necessary for supporting the card; and that—with small enough needles to admit of the complete application of the late Astronomer-Royal's principles of correction—the length of period required for steadiness at sea is to be obtained, without sacrificing freedom from frictional error, by giving a large diameter to the compass card, and by throwing to its outer edge as nearly as possible the whole mass of rigid material which it must have to support it.

* The vibrational period or the period (as it may be called for brevity) of a compass, is the time it takes to perform a complete vibration, to and fro, when deflected horizontally through any angle not exceeding 30° or 40°, and left to itself to vibrate freely. The time of vibration is the mass multiplied into the square of the radius.

† Taking a fly-wheel by way of example, the radius, of the rim in which the whole mass must be collected without altering the importance of the inertia relatively to rotation round the axis, is technically defined as the radius of gyration.



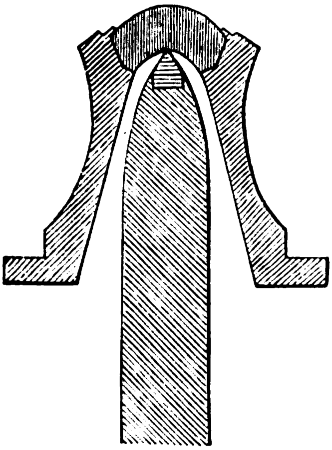
In the compass card, of which a representation is here given, these qualities are acquired by supporting its outer edge on a thin rim of aluminium—a strong but exceedingly light metal—and its inner parts on thirty-two silk threads stretched from the rim to a small central boss of aluminium, making thirty-two spokes, as it were, of the wheel.

Description of card.

The silken threads being an elastic medium between the point of suspension and so much of the weight as is accumulated in the rim, the hammering action of the card on the pivot during vertical shocks or tremors is mitigated; and to a smaller extent lateral shocks also, but, owing to the threads being in tension, this last effect is not so pronounced. Speaking generally, in being propagated through the flexible structure of the card, the energy of a disturbing force is absorbed and nullified. This object is further attained by slinging the bowl and its contents from an elastic copper grommet. In the 1892 patent the suspension is different.

The card itself is of thin strong paper, and all the central parts of it are cut away, leaving only enough to shew conveniently the ordinary points and degree divisions of the compass. The central boss consists of a thin disc of aluminium, with a hole in its centre, which rests on the projecting lip of a small inverted cup made of the same metal, and mounted with a sapphire cap, which, in its turn, rests on a fixed iridium* point, and so sustains the entire card.

CAP AND BEARING POINT.



Eight small needles, from 3½ to 2 inches long, made of thin steel wire, and weighing in all 54 grains, are fixed like the steps of a rope ladder on two parallel silk threads, and slung from the aluminium rim by other silk threads rove through eyes in the ends of the outer pair of needles. Being slung underneath keeps the centre of gravity low, which, in its turn, tends to correct the 'dip' in high latitudes.

The weight of the central boss, aluminium cup, and sapphire cap, amounts in all to about five grains. It need not be more for a 24-inch than for a 10-inch compass.

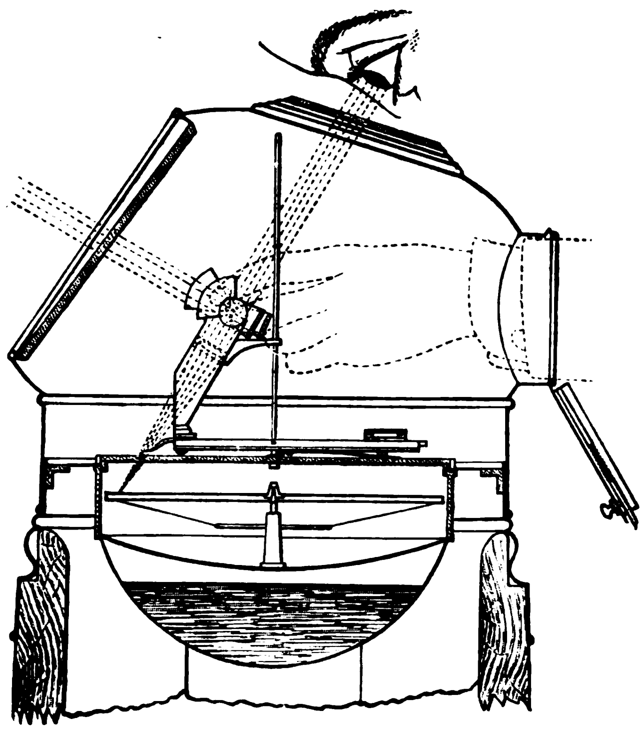
Weight of card. For the 10-inch compass, the whole weight on the iridium point, including rim, card, silk threads, central boss, and needles, is about 180 grains. The limit to the diameter of the card depends upon the quantity of soft iron that can be introduced, without inconvenience, on the starboard and port sides of the binnacle, to correct the quadrantal error. If, as sometimes may be advisable in the case of a pole or masthead compass, it be decided to leave the quadrantal error uncorrected, the diameter of the compass card may be anything from 12 to 24 inches, according to circumstances. A 24-inch card on this principle will un- **Size of card.**

* The hardest metal known.

doubtedly have less frictional error or "sluggishness" for the same degree of steadiness than any smaller size; but a 12-inch card works well even in very unfavourable circumstances, and it will rarely, if ever, be necessary to choose a larger size, unless for convenience of the steersman, to enable him to see the divisions, whether points or degrees.

Specimens of 12-inch, 15-inch, and 24-inch Pole compasses have been made. The last mentioned may be looked at with some curiosity as being probably the largest compass in the world, and would require a bowl like a washing tub. It will no doubt be properly condemned as too cumbrous for use at sea, even in the largest ship, but there can be no doubt it would work well in a position in which a smaller compass would be made to oscillate very wildly by the motion of the ship.

Improved Binnacle-top. The subjoined diagram represents the 10-in. Standard Compass and upper portion of binnacle. The Azimuth-Mirror is shipped ready for observing, and it will be noticed that a small door in rear of the helmet gives access to it, so that in bad weather an azimuth or bearing can be taken without removing the binnacle-top.



The "period" of free oscillation of Lord Kelvin's 10-inch compass is in England about 40 seconds, which is more than double the "period" of the A card of the Admiralty Standard Compass, and is considerably longer than that of the ordinary 10-inch compass so much in use in merchant steamers. The maximum "period" of the roll of a ship in a heavy beam sea is found not to exceed 20s., and from that of Lord Kelvin's compass being so much longer, the two can never synchronise, which is just what is wanted. The new compass ought, therefore, according to theory, to be much steadier in a heavy sea than either the Admiralty compass or the *ordinary* 10-inch compass, and actual experience at sea has thoroughly fulfilled this promise. It has also proved very satisfactory in respect to frictional error; so much so that variations of a steamer's course of less than half a degree—or, say, the 1,000th part of the entire circle—are shown instantly and surely, even if the engines be stopped, and the water perfectly smooth.

Steadiness of card.

Frictional error.

With the small needles of Lord Kelvin's compass, the complete practical application of the late Astronomer-Royal's principles of correction is easy and sure: that is to say, correctors can be applied so that the compass shall be free from Deviation on all points; and these correctors can be easily and surely adjusted at sea as need may arise, so as to remove the smallest discoverable error growing up, whether through change of the ship's own magnetism or of the magnetism induced by the earth according to the geographical position of the ship.

To correct the quadrantal error, a pair of solid or hollow iron globes are placed on proper supports attached to the binnacle. This mode is preferable to the usual chain boxes, because a continuous globe or spherical shell of iron is more regular in its effect than a heap of chain, and because a considerably less bulk of the continuous iron suffices to correct the same error.

Quadrantal correctors.

When, in a first adjustment in a new ship, or in a new position of a compass in an old ship, the quadrantal error has been found from observation, by the ordinary practical methods, it is to be corrected by placing a pair of globes in proper positions according to the table on next page.

TABLE FOR CORRECTION OF QUADRANTAL ERROR.

Error to be Corrected.	Distances of the Nearest Points of Globes from Centre of Compass.										
	10-inch Globes.	9-inch Globes.	8½-inch Globes.	8-inch Globes.	7½-inch Globes.	7-inch Globes.	6½-inch Globes.	6-inch Globes.	5½-inch Globes.	5-inch Globes.	4½-inch Globes.
°	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1	22·80	20·52	19·38	18·24	17·10	15·96	14·82	13·68	12·54	11·40	10·26
1½	19·30	17·36	16·39	15·42	14·46	13·50	12·54	11·57	10·61	9·65	8·66
2	17·06	15·36	14·51	13·66	12·81	11·95	11·10	10·24	9·39	8·53	7·68
2½	15·48	13·94	13·16	12·39	11·61	10·84	10·07	9·29	8·52	7·74	6·97
3	14·28	12·84	12·13	11 42	10·70	9·99	9·28	8·57	7·85	7·14	6·42
3½	13·32	11·98	11·32	10·65	9·99	9·32	8·65	7·99	7·32	6·66	5·99
4	12·52	11·26	10·63	10·01	9·39	8·76	8·13	7·51	6·88	6·26	5·63
4½	11·84	10·66	10·07	9·47	8·88	8·29	7·70	7·10	6·51	5·92	5·33
5	11·26	10·13	9·57	9·01	8·45	7·88	7·32	6·75	6·19	5·63	5·07
5½	10·76	9·67	9·13	8·59	8·06	7·52	6·99	6·45	5·91	5·38	4·84
6	10·40	9·27	8·75	8·24	7·72	7·21	6·70	6·18	5·66	5·14	4·53
6½	9·90	8·91	8·41	7·92	7·42	6·93	6·44	5·94	5·44	4·95	4·46
7	9·54	8·58	8·10	7·63	7·15	6·67	6·20	5·72	5·24	4·77	4·29
7½	9·20	8·28	7·82	7·36	6·90	6·44	5·98	5·52	5·06	4·60	4·14
8	8·90	8·01	7·57	7·12	6·68	6·23	5·79	5·34	4·90	4·45	4·01
8½	8·62	7·76	7·33	6·90	6·47	6·04	5·60	5·17	4·74	4·31	3·88
9	8·36	7·53	7·11	6·69	6·27	5·86	5·44	5·02	4·60	4·18	3·76
9½	8·12	7·32	6·91	6·50	6·09	5·69	5·28	4·87	4·47	4·06	3·66
10	7·90	7·11	6·72	6·32	5·93	5·53	5·14	4·74	4·35	3·95	3·55
10½	7·70	6·93	6·54	6·16	5·77	5·39	5·00	4·62	4·23	3·85	3·46
11	7·50	6·75	6·37	6·00	5·62	5·25	4·87	4·50	4·12	3·75	3·37
11½	7·32	6·58	6·22	5·85	5·49	5·12	4·76	4·39	4·02	3·66	3·29
12	7·14	6·43	6·07	5·71	5·36	5·00	4·64	4·29	3·93	3·57	3·22

TABLE FOR CORRECTION OF QUADRANTAL ERROR, FROM 12 TO 16 DEGREES.

Error to be Corrected.	12-inch Globes.	11-inch Globes.
	Inches.	Inches.
12°	8·61	7·89
12½	8·42	7·72
13	8·23	7·55
13½	8·05	7·38
14	7·89	7·23
14½	7·73	7·09
15	7·58	6·95
15½	7·44	6·82
16	7·30	6·69

When the quadrantal error has been thus once accurately corrected, the correction is perfect to whatever part of the world the ship may go, and requires no adjustment at any subsequent time, *except in the case of some alteration in the ship's iron*, or of iron cargo or ballast sufficiently near the compass to introduce a sensible change in the quadrantal error.

Difficulty in correcting Quadrantal error.

The vast simplification of the deviations of the compass effected by a perfect correction of this part of the whole error, has not, until now, been practically appreciated, because, in point of fact, with other compasses this correction has rarely, if ever, been successfully made for all latitudes. The pair of large needles of the compass ordinarily used in merchant ships does not—as shewn by Captain Sir F. Evans, R.N., F.R.S., and Mr. A. Smith, M.A., F.R.S.—admit of the correction of the quadrantal error in the usual manner, without the introduction of a still more pernicious error, depending on the nearness of the ends of the needles to the masses of chain, or of soft iron of whatever kind, applied on the two sides of the compass to produce the correction. The Admiralty Standard Compass, with its four needles proportioned and placed according to Archibald Smith's rule, is comparatively free from this fault; so also is the compass described in Chapter III.; but even with them, and still more with the stronger needles of the 12-inch compasses of merchant ships, there is another serious cause of failure, depending on the magnetism induced in the iron correctors by the reflex action of the compass needles, in consequence of which, if the quadrantal error is accurately corrected in one latitude, it will be found over-corrected in high

magnetic latitudes, and under-corrected in the neighbourhood of the magnetic equator.

Lord Kelvin's compass is specially designed to avoid both these causes of failure in the correction of the quadrantal error: and experiment has conclusively shewn that, with it, the correction by such moderate masses of iron as those indicated in the preceding table, is practically perfect, not only in the place of adjustment, but in all latitudes.

Short needles. In the theory of compass adjustment the needles are regarded as being infinitely small. This is of course unattainable, but a rule may be deduced from it as follows:—that the shorter the needles the better, *so long as they are able to do their work.*

When the card is in position, between its soft iron quadrantal correctors, the needles in Lord Kelvin's compass are small as compared with the mass of these correctors, and are also remote from them. Being thus remote, two things happen:—one is, that they are in a practically uniform magnetic field, for this reason, that, as you increase the distance from the correctors, you get a greater parallelism in the lines of magnetic force, though, on the other hand, the force is enormously diminished in its intensity, in obedience to the law that "magnetic attractions and repulsions are inversely as the squares of the distances." There remains, however, amply sufficient force to operate upon a card of such light construction. The same thing exactly holds good with regard to the permanent steel magnets for correcting the semi-circular error.

Octantal deviation. The next thing is, that the short needles do not induce magnetism to any appreciable amount in the correctors by their reciprocal action on each other. If they did, it would, to a certain extent, destroy the intended effect of the correctors. When a magnet acts upon a mass of soft iron, the law above quoted is modified, as the attraction in such cases is inversely proportional to the distance between the magnet and the iron. When the correctors are too close to the needles, as in the old system, 'octantal' deviation is the result. It will be seen, therefore, that, with the long needles in vogue before Lord Kelvin revolutionised the whole business, a perfect compensation of the quadrantal error was *impossible.*

When once the quadrantal error has been accurately corrected, there is no difficulty about the semi-circular deviation, since the binnacle is provided with proper appliances for effecting this part of the adjustment in a speedy and certain manner, and with the minimum of trouble.

The objection has often been made to the use of correcting magnets, that their re-adjustment at sea leaves the navigator without the means of judging, when he returns from a foreign voyage, as to how much of the existing error found on re-adjustment depends on changes which have been made in the correcting magnets, and how much on changes of the ship's own magnetism. This objection has been met, in Lord Kelvin's binnacle, by providing that at any moment the correctors can be removed or set to any degree of power to which they may have been set at any time in the course of the voyage, and again re-set to their last position with perfect accuracy.

Correcting Magnets.

The appliances for changing the adjustment are under lock and key, so that they can never be altered, except by the captain or some properly authorised officer.

Further to facilitate the use of the correctors, they have scales affixed, which are graduated accurately to correspond to definite variations of the effect which they produce on the compass. Thus as soon as the error has been determined by an azimuth or any other mode, the corrector may at once be shifted to a position certain to compensate it. Of course, whoever is performing the adjustment will satisfy himself of its correctness by a second observation.

Graduated scales.

The compass-bowl is attached to the suspensory rings by knife-edge gimbals. This gives great ease of movement, the object being to keep the compass steady in a sea-way and preserve its horizontality. But since with knife-edges the friction is very small, if the ship were pitching or rolling much, the bowl would be set into rapid oscillation, and its isochronism with the card would be destroyed; in fact, the suspension would be *too* free for the intended purpose. It therefore becomes necessary to calm the vibrations in some way or another. This is ingeniously accomplished by giving the bowl a false bottom, *partially* filled with a viscous fluid—preferably castor oil—which acts as a 'drag' on the inner surfaces. Thus the evil which would result from the over-great freedom of the knife-edge bearings in the gimbal-rings is cured, not by the addition of weight as such, but by the action of what may correctly be termed a "fluid friction-brake." This contrivance consumes, so to speak, the surplus energy of the bowl, and keeps its motion within bounds. A double bottom *wholly* filled with liquid would not have so good an effect as one partially filled; besides, in a hot climate it would be apt to burst. Of course the requisite amount of brake power had, in the first instance, to be ascertained by actual experiment.

Knife-edge gimbals.

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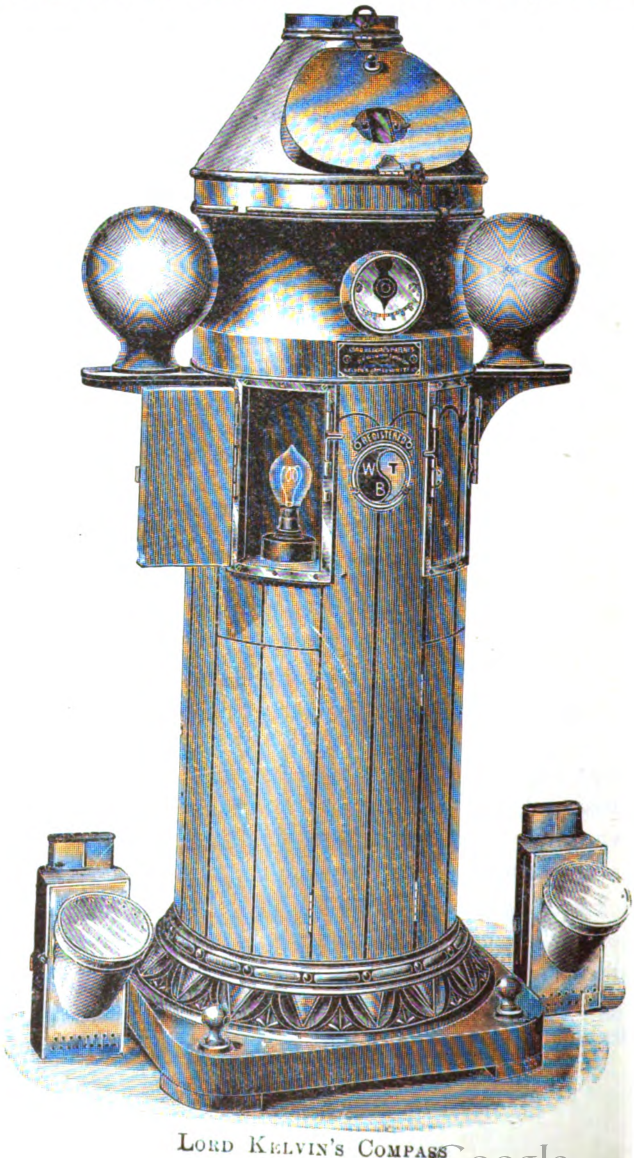
The glass cover is strong, and well secured to the bezel by means of four milled-headed screws; the latter is made to fit air-tight to the bowl, so that dampness cannot get in to cloud the glass; there is consequently never any occasion to meddle with the card. The brass helmet is secured to the binnacle rim without the aid of screws, and can be instantaneously slued to the right or left to get rough eye bearings—a great improvement on the old plan, where the screws were always either mislaid or lost. The binnacle lamps are so placed that the light falls on the *far* side of the card and on the lubber's point, but not *on the eyes of the observer.* In fact, all the details necessary to a satisfactory

Distinct vision secured.



LORD KELVIN'S COMPASS.

compass have been carefully considered, and well carried out, and it may therefore be regarded as *the* compass of the civilised world at this date. All credit to the inventor! The diagram gives a good general idea of the latest development.

2. THE AZIMUTH-MIRROR.

Some years ago an important objection was raised by Captain Sir Frederick Evans, R.N., against the use of quadrantal correctors in the Navy, that they would prevent the taking of bearings by the prismatic azimuth-ring which forms part of the Admiralty Standard Compass. The azimuth-mirror depicted in the diagram on page 215 was designed to obviate that objection, and happily disposes of many others also.

Its many advantages.

Its use, even for taking bearings of objects on the horizon, is not interfered with by the globes constituting the quadrantal correctors, even if their highest points rise as high as five inches above the glass of the compass-bowl.

Principle upon which it is based

It is founded on the principle of the camera lucida. The observer, when taking a bearing, turns the instrument round its vertical axis until the mirror and lens are fairly opposite to the object. He then looks through the lens at the degree divisions of the compass-card, and turns the mirror round its horizontal axis till he brings the image of the object to fall on the card. He then reads directly on the card the compass bearing of the object.

Besides fulfilling the purpose for which it was originally designed, to allow bearings to be taken without impediment from the quadrantal correctors, the Azimuth-Mirror has a great advantage in not requiring any adjustment of the instrument such as that by which, in the prismatic azimuth-ring, the hair is brought to exactly cover the object. The focal length of the lens in the Azimuth-Mirror is about 12 per cent. longer than the radius of the circle of the compass-card, and thus, by an elementary optical principle, it follows that two objects a degree asunder on the horizon will, by their images seen in the Azimuth-Mirror, cover a space of $1^{\circ}\cdot 12$ of the compass-card seen through the lens. Hence, turning the instrument round its vertical axis through one degree will only alter the apparent bearing of an object on the horizon by $0^{\circ}\cdot 12$. Thus it is not necessary to adjust it *exactly* to the direct position for the bearing of any particular object, though as a matter of fact it can be done absolutely without trouble of any kind. If it be designedly put even as much as 9° awry on either side of the direct position, the error on the bearing would hardly amount to a degree.

Focal length.

If the instrument were to be used solely for taking bearings of objects on the horizon, the focal length of the lens would be made exactly equal to the radius of the circle of the card, and thus even the small error of 0°·12 in the bearing for each degree of error in the setting would be avoided. But one of the most important uses of the azimuth instrument at sea is to correct the compass by bearings of sun, moon, or stars, at altitudes of from 0° to 50° above the horizon. The actual focal length is accordingly chosen to suit an altitude of about 27°, this being the angle whose natural secant is 1°·12. Thus if two objects, near together, whose altitudes are 27°, or thereabouts, and difference of azimuth is 1°, should be taken simultaneously in the Azimuth-Mirror, their difference of bearings will also be shewn as 1° by the divided circles of the compass card seen through the lens.

Exact setting unnecessary.

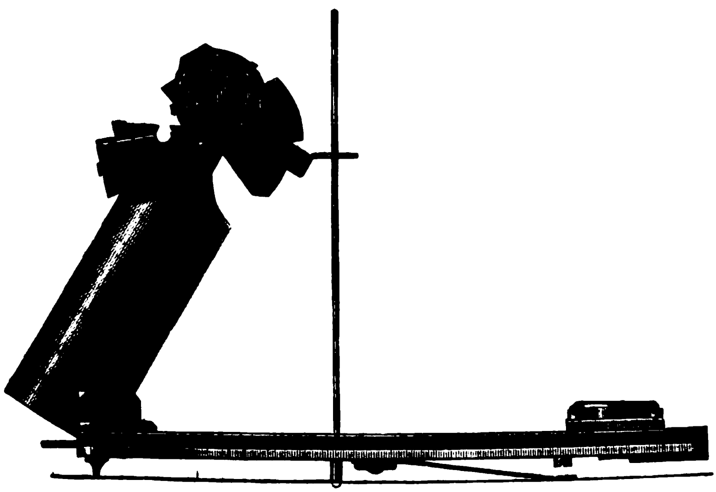
Hence, for taking azimuths of bodies at an altitude of 27°, or thereabouts, no setting of the Azimuth-Mirror by turning round the vertical axis is necessary, except just to bring the object into the field of view, when its bearing will immediately be seen accurately shewn on the edge of the compass-card.

This is a very valuable quality for use in rough weather at sea, or when there are flying clouds which just allow a glimpse of the object to be caught, without allowing time to perform an adjustment, such as that of bringing the thread of the ordinary azimuth ring, or rather, the estimated middle of the space traversed by the thread in the rolling of the ship, to coincide with the object. The same degree of error as on the horizon, but in the opposite direction, is produced by imperfect setting in taking the bearing of an object at an altitude of 38°.

Thus, for objects from the horizon up to 38°, the error in the bearing is less than 12 per cent. of the error in the setting. For objects at a higher altitude than 38° the error rapidly increases, but it is always easy, if desired, to set the instrument accurately by turning it so that the red indicator below the lens shall point exactly, or nearly so, to the position on the divided circle of the compass-card occupied by the image of the object; indeed it always suggests itself as the natural thing to do. *In no case, however, is it recommended, with this or any other instrument, to take azimuths above 30°.*

For taking star bearings the Azimuth-Mirror has the great advantage over the prismatic azimuth-ring, with its then invisible thread, that the image of the object is thrown directly on the illuminated scale of the compass-card. The degree of illumination may be made less or more, according to faintness or brilliance of the object, by holding a binnacle lamp in the hand at a greater or less distance, and letting its light shine only on the portion of the compass-card from which the bearing will be taken. Indeed, with the Azimuth-Mirror, it is almost easier to take the bearing of a planet or moderately bright star by night, than of the sun by day; the star is seen as a fine point on the margin of the card, and it is easy to read off its position instantly by estimation to the tenth of a degree. You will certainly not attain to this precision on board a ship under way ; nor is it required. Contrasted with other instruments

The most convenient as well as the most accurate method of all, however, is the sun, when bright enough and high enough above the horizon to throw a good shadow on the compass-card. For this purpose is the brass shadow-pin which, when required, is inserted in the framework of the instrument, in such a position that when the Azimuth-Mirror is properly shipped on the glass of Stile or Shadow-Pin



the compass-bowl, the pin is perpendicular to the glass, and accurately centred over the bearing point of the card. A small circular level attached to the instrument, shewn on right of diagram, tells at once whether the compass-bowl is out of balance, but in practice, unless with a strong wind blowing against the mirror, this is seldom the case. Any way the remedy is simple: a small weight of any kind—say a penny piece—may be moved about on the glass till the bubble of the level remains in the centre of its run, and taken away after the observations are completed. A shelter-cloth is obviously the right thing in breezy weather. How to restore balance.

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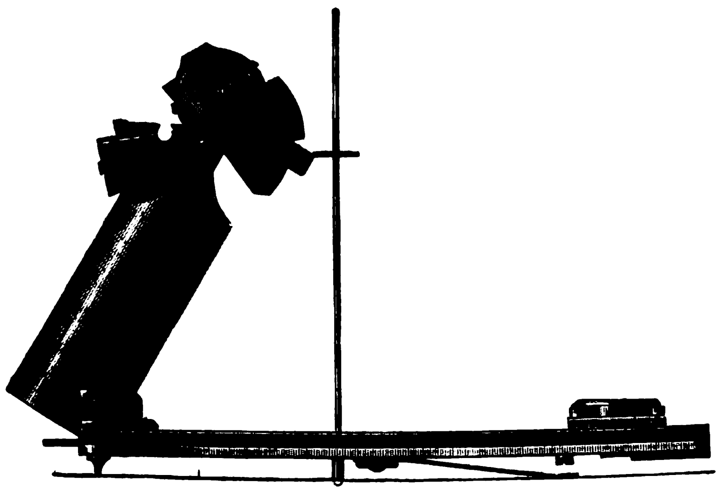


the compass-bowl, the pin is perpendicular to the glass, and accurately centred over the bearing point of the card. A small circular level attached to the instrument, shewn on right of diagram, tells at once whether the compass-bowl is out of balance, but in practice, unless with a strong wind blowing against the mirror, this is seldom the case. Any way the remedy is simple: a small weight of any kind—say a penny piece—may be moved about on the glass till the bubble of the level remains in the centre of its run, and taken away after the observations are completed. A shelter-cloth is obviously the right thing in breezy weather.

How to restore balance.

Another advantage of the Azimuth-Mirror, particularly important for taking bearings at sea when there is much motion, is that, with it, it is not necessary to look through a small aperture in an instrument moving with the compass-bowl, as in the ordinary prismatic arrangement still fitted to the standard compasses of many of the best merchant vessels. In using the Azimuth-Mirror, the eye may be placed at any distance, say from an inch or so to two or three feet from the instrument, according to convenience, and in any position, and may be moved about freely through a considerable range, on either side of the line of direct vision through the lens, without at all disturbing the accuracy of the observation.

Observer's freedom of action.

This last condition is secured by the lens being fixed in such a position that the divided circle of the compass-card is in its principal focus. Thus the virtual image of the divided circle is at an infinite distance, and the images of distant objects seen coincidently with it by reflection in the mirror, show no shifting on it, that is to say, no parallax, when the eye is moved from the central line to either side.

The Azimuth-Mirror is fitted with coloured shades for use when observing the sun; and for bearings of objects on or near the horizon, the mirror can be reversed in a second of time, so as to make the reflected image of the degrees on the card coincide with the object seen by direct vision over the top of the mirror. There are, therefore, two methods of getting the bearings of objects near the horizon, and the observer can please himself as to which he employs. In describing the invention, the word 'mirror' has been used throughout: possibly to some this may convey the idea that the reflector is a plane glass quicksilvered at the back. Indeed this was the original form, but, finding that rain and spray quickly impaired its powers, Lord Kelvin substituted what is a great improvement, namely, a totally-reflecting prism. In 'total reflection' there is no loss of light from absorption or transmission, and accordingly it produces the greatest brilliancy. A clean pocket handkerchief applied with ordinary care will clean both lens and prism.

Bearings by reversal.

This little instrument is the quintessence of all that is required to obtain accurate bearings of bodies terrestrial or celestial. When not in actual use it fits into a neat mahogany box.

8. AN ADJUSTABLE DEFLECTOR, FOR COMPLETELY DETERMINING THE COMPASS ERROR WHEN SIGHTS OF HEAVENLY BODIES, OR COMPASS MARKS ON SHORE, ARE NOT AVAILABLE, AS FOR EXAMPLE IN FOG, OR ON A CLOUDY NIGHT.

About forty-five years ago, Sir Edward Sabine gave a method in which, by aid of deflecting magnets properly placed on projecting arms attached to the prism-circle of the Admiralty Standard compass, a partial determination of the error of the compass could be made at any time, whether at sea or in harbour, without the aid of azimuths of heavenly bodies or transit marks on shore. **Origin.**

The adjustable magnetic deflector invented by Lord Kelvin, is designed for carrying out in practice Sabine's method more rapidly and more accurately, and for extending it, by aid of Archibald Smith's theory, to the complete determination of the compass error, with the exception of the constant term "A" of the Admiralty notation, which in almost every practical case is zero, and which, in a well made compass, and with a correctly placed lubber line, can only have a sensible value in virtue of some very marked want of symmetry of the iron work in the neighbourhood of the compass. When it exists, it can easily be determined once for all, and allowed for as if it were an index-error of the compass card, and it will, therefore, to avoid circumlocution in the statements which follow, be either supposed to be zero, or allowed for as index-error. **Improved instrument.**

The new method of adjustment is founded on the following four principles:— **Principle upon which founded.**

(1.) If the directive force on the compass needles be constant on all courses of the ship, the compass is correct on all courses.

(2.) If the directive force be equal on five different courses, it will be equal on all courses.

(3.) Supposing the compass to be so nearly correct, or to have been so far approximately adjusted, that there is not more than eight or ten degrees of error on any course, let the directive forces be measured on two opposite courses. If these forces are equal, the compass is free from semicircular error on the two courses at right angles to those on which the forces were measured; if they are unequal, there is a semi-circular error on the courses at right angles to those on which the forces were measured, amounting to the same fraction of the radian that the difference of the measured forces is of their sum.*

* The unit of circular measure is an angle which is subtended at the centre of a circle by an arc equal to the radius of that circle. Such an angle goes by the name of the 'radian,' and is equal to $\frac{180^\circ}{3\cdot1416}$ or 57°·3 nearly.

(4.) The difference of the sums of the directive forces on opposite courses in two lines at right angles to one another, divided by the sum of the four forces, is equal to the proportion which the quadrantal error, on the courses 45° from those on which the observations were made, bears to 57°·3.

Its use easily learned.

The deflector may be used either under way or in swinging the ship at buoys. The whole process of correcting the compass by it is performed with the greatest ease and rapidity when under way, with sea room enough to steer steadily on each course for a few minutes, and to turn rapidly from one course to another.

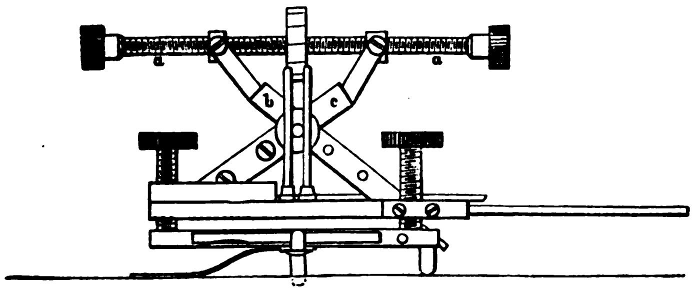
For each operation the ship must be kept on one course for three or four minutes, if under way, by steering by aid of an auxiliary compass; otherwise by hawsers in the usual manner if swinging at buoys, or by means of steam-tugs. A variation of two or three degrees in the course during the operation will not make a third of a degree of error in the result, as regards the final correction of the compass.

The deflector reading is to be taken according to the detailed directions in the printed "Instructions," accompanying the instrument. This reading may be taken direct on the small straight scale in the lower part of the instrument. The divided micrometer circle at the top is scarcely needed, as it is easy to estimate the direct reading on the straight scale to a tenth of a division, which is far more than accurate enough for all practical purposes. This reading with a proper constant added gives, in each case, the number measuring in arbitrary units the magnitude of the direct force on the compass for the particular course of the ship on which the observation is made.

Amount of accuracy attainable.

The adjustment by aid of the deflector is quite as accurate as it can be by aid of compass marks or sights of sun or stars, though on a clear day, at any time when the sun's altitude is less than 40°, or on any clear night, the adjuster will of course take advantage of sights of sun or stars, whether he helps himself also with the deflector or not.

The deflector consists of two pairs of small steel bar magnets *bc* attached to brass frames, jointed together and supported on a sole-plate, which is placed on the glass cover of the compass-bowl when the instrument is in use. The two frames carry pivoted screw nuts, with right and left handed screws. A brass shaft *aa* with right and left handed screws cut on its two halves, works in these nuts, so that when it is turned in either direction one of the two pairs of north poles is brought nearer to, or farther from, one of the two pairs of south poles, while the other two pairs of north and south poles are all in the line of the hinged joint between the two frames. This arrangement, which constitutes, as it were, a **Position of Poles.**



jointed horse-shoe magnet, adjustable to greater or less magnetic moment by increasing or diminishing the distance between its poles through the action of the screw, is so supported on its sole-plate that, when this is properly placed on the glass of the compass-bowl, the effective poles move to and fro horizontally about half an inch above the glass on the two sides of a vertical plane through its centre.

Sole Plate

The sole-plate rests on three feet, one of which, under the centre of gravity of the deflector, rests in the conical hollow in the centre of the glass. It is caused to press with a small part of its whole weight on the other two feet by a brass spring attached to the bottom of the sole-plate, on the other side of the centre from these two feet, and pressing downwards on the glass. This is shewn at the bottom left-hand side of the diagram.

A brass pointer attached to the sole-plate marks the magnetic axis of the deflector. It projects from the centre, on the side of which is the pair of south poles. This is shewn near the bottom of the right-hand side of the diagram. Thus if the deflector be properly placed on the glass of the compass-bowl, with the pointer over the north point of the card, it produces no deflection, but augments the directive force on the needle.

To make an observation, the deflector is turned round in either direction, and the north point of the card is seen to follow the pointer.

Power, how regulated.

The power of the deflector is adjusted by the screw, so that when the pointer is over the east or west point of the card, the card rests balanced at some stated degree of deflection, which for the regular observation on board ship is chosen at 85°. A scale, measuring changes of distance, is then read and recorded.

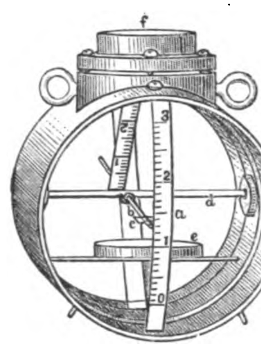
For adjusting a compass by the aid of the deflector, the correcting magnets are so placed that the deflector reading, found in the manner just described, shall be the same for the four cardinal courses; and also for one of the quadrantal courses, if the compass is sufficiently affected by unsymmetrically placed iron to shew any sensible amount of the "E" constituent of quadrantal error.

Magnetic Scale-value of deflector.

When the deflector is to be used for determining the *amount* of an *uncorrected* error, according to principles (3) and (4) above, the magnetic value of its scale reading must be determined by experiment. This is very easily done on shore, by observations of its deflecting power, when set by its screw to different degrees of its scale.

Under a good teacher, the practical use of this invaluable instrument is soon mastered, and after reasonable practice with it there is no particular difficulty.

4. NEW FORM OF MARINE DIPPING NEEDLE, FOR FACILITATING THE CORRECTION OF THE HEELING ERROR.



Vertical Force.

The marine dipping needle is used for comparing the "vertical force"* on shore with the "vertical force" on board, thereby enabling the vertical magnet in the binnacle to be so adjusted as to correct the heeling error. It consists of a magnetised steel bar *b*,

* "Vertical force" is a short expression for the vertical component of the earth's magnetic force. It is reckoned as positive when the direction of its action upon a red pole is downwards, as in the northern hemisphere; and negative when upwards, as in the southern hemisphere. At the magnetic equator it is zero. The amount of the vertical force at any place is calculated by multiplying the value of the horizontal force, given by the chart of lines of equal horizontal force shewn opposite page 610, by the tangent of the dip as given by the chart of lines of equal magnetic dip. Thus, for example, the tangent of the dip for the South of England being 2·44, and the horizontal force there being called unity, the vertical force there is 2·44. The tangent of the dip at Aden is ·09, and the horizontal force there is 1·95; hence the vertical force there is ·1755, or about $\frac{1}{14}$ of the vertical force at the South of England.

supported on knife-edges, so as to be capable of turning round a horizontal axis *a*. Before being magnetised, the needle is balanced so as to be truly horizontal when resting on the knife-edges. When magnetised, the north or red end dips, and a paper weight *c* is fitted on the southern half of the needle to restore its balance. This weight can be slid along the needle whenever a change in the "vertical force" renders it necessary. **Marine Dipping Needle.**

To correct the heeling error on board ship, the instrument is first taken on shore, to a spot free from Local Attraction, and the paper weight adjusted, so that with the bubble of the spirit-level *f* in the centre, the needle is exactly horizontal when resting on the knife-edges. There are marks by which this can be effected.

If the mean directive magnetic force on board were the same as the directive force on shore, the instrument would now be taken on board and placed in the binnacle in such a position that its needle would now occupy the place previously occupied by the needles of the compass card, which latter has to be temporarily removed. It would then be found, probably, that the needle had departed from its horizontal position, and the vertical magnet in the binnacle would have to be moved up or down to restore the level, always bearing in mind to keep the bubble in the centre. But it so happens that the mean force is generally from $\frac{1}{10}$ to $\frac{1}{20}$ less on board than it is on shore, and in order to allow for this, the paper weight must be pushed nearer to the centre of the needle by $\frac{1}{10}$ or $\frac{1}{20}$. This can be done by turning the instrument upside down, so as to make the needle lie along a scale graduated from the centre outwards. This being accomplished, the instrument is taken on board ship, and the compass-bowl having been removed from the binnacle, the instrument is slung by four lanyards, so that its needle shall take up the exact place before occupied by the needles of the compass-card. The vertical magnet is then slid up or down until the needle of the instrument rests truly horizontal when the bubble of the spirit-level is in the centre. **How to use it.**

5. NAVIGATIONAL SOUNDING MACHINES.

These important instruments have already been briefly described on pages 168-171, but further details will be both useful and interesting.

The sounding machines in question are designed for the purpose of getting soundings from a vessel running at high speed in water of any depth not exceeding 100 fathoms.

Sounding difficulties.

The difficulties to be overcome are twofold: first, to get the sinker to the bottom; and secondly, to get sure evidence as to the depth to which it has gone down. For practical navigation a third difficulty must also be met, and that is to bring the sinker up again; for—although in deep-sea surveys, in water of more than 3,000 fathoms depth, it is advisable, even when pianoforte wire is used, to leave the thirty or forty pounds sinker at the bottom, and bring back only the wire with attached instruments—it would never do in practical navigation to throw away a sinker every time a cast is taken; and its loss, whether with or without any portion of the line, ought to be a rare occurrence in many casts.

The first and third of these difficulties seemed insuperable; at all events, they had not hitherto been overcome with hemp rope for the sounding line, except for very moderate depths, and for speeds much under the speed of a modern fast steamer.

Pianoforte wire.

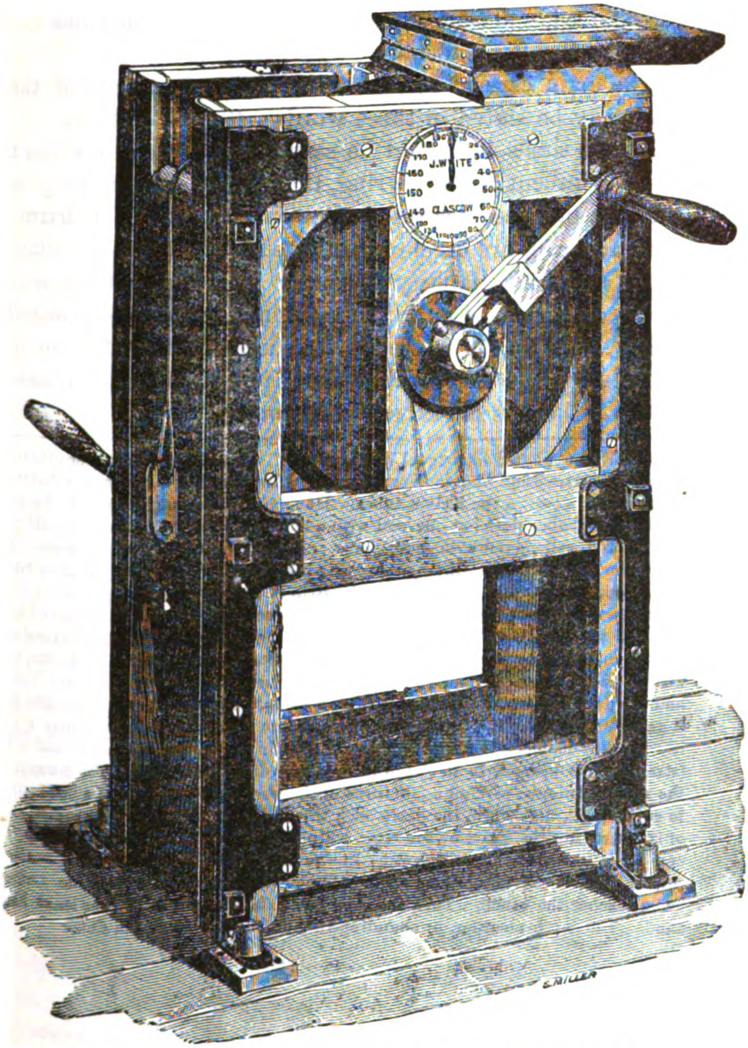
Taking advantage of the great strength, and the small and smooth area for resistance to motion through the water, presented by pianoforte wire, Lord Kelvin succeeded in overcoming all these difficulties, and with either of his sounding machines a cast in 100 fathoms can readily be got from a vessel running 15 or 16 knots an hour.

The pianoforte wire weighs $1\frac{3}{4}$ lbs. per 100 fathoms, and bears, when fresh, from 230 to 240 lbs. without breaking; its diameter is only ·02 of an inch. Formerly it was preserved from rusting by immersion in a tank of lime-water forming a fixed part of the entire machine; but the same end is now obtained by galvanising, and, barring accidents, the wire will last an indefinite time. The most recent pattern is shewn in the engraving on next page.

Things requiring attention.

When taking a cast, not only is the wire *seen* to slacken on the sinker touching the bottom, but the *sound* is quite different: on a dark night this little circumstance is of value, as the drum must then be stopped without delay. In winding in, to make the wire lie evenly on the drum, one man should guide it with a piece of canvas.

In the use of the compressed air depth-guage, be sure when removing the slender glass tube from its case *to keep the open end down;* also, whilst reading off the depth by the box-wood scale, maintain it in this position (vertical, or nearly so), and take the *lowest* part of the red mark for reading.



IMPROVED FORM OF LORD KELVIN'S SOUNDING APPARATUS.

If the Barometer	stands at	$29\frac{3}{4}$	inches, add	one fathom in	40.
"	"	30	"	"	30.
"	"	$30\frac{1}{2}$	"	"	20.
"	"	31	"	"	15.

This correction is not needed when the "Depth-Recorder" is used.

Should the sinker get jammed in a cleft of rock at the bottom, or against the side of a boulder, the wire and its appendages will inevitably be lost. Such an accident must obviously be very rare indeed, and any other form of sounding machine is equally liable to the same mishap.

The main care in respect to avoiding breakage of the single wire may be stated in three words—*Beware of kinks.*

At all times it should be scrupulously seen to, when the cod-line* is unbent from the ring, that the ring is securely seized to the hole provided for the purpose in the rim of the drum. If the wire and ring are carelessly allowed to knock about slack on the drum, there is a liability to some part getting a turn, which may at the next cast be pulled into a kink, and then—*farewell to the sinker.* All that is wanted in the successful use of these machines is ordinary care and intelligence; lack of these two qualities will occasion the loss of sinkers *and temper.*

* Small line, plaited like signal haulyard stuff, is preferable, as it keeps itself free from turns. Captain John Martin, Norwegian ss. *Akershus*, has suggested a substitute for the chromate of silver in the Kelvin tubes. He used a water-gauge glass of the same length as the usual tube, closed at one end with a flat piece of cork, having a small piece of rag over it, and well coated with sealing-wax. A narrow strip of drawing paper, marked up its centre with a straight line by a copying-ink pencil, was shoved up this tube to serve as a blank scale. The lower end of the strip is turned over the edge of the tube, and kept thus fastened with a piece of cotton to prevent displacement of the strip as the water is forced up the tube. The guard to put the gauge glass in was made from an old condenser tube, and a piece of boiler tube filled with scrap iron and cement, or concrete, made a cheap and handy sinker. The aniline line indicates the height by discoloration; and the depth is read off the boxwood scale. Used simultaneously with the Kelvin tube it gave the same depth. A strip may be dried and used again by making a new line on it. To prevent kinks in the wire Captain Martin recommends the use of a fore-runner (stray line) of hemp with an eye in it like the ordinary lead line. The hemp is joined to the wire as follows:—Wind a few turns of the wire round the end of a belaying-pin so as to get a spiral, then worm the hemp with this, filling up the lay of the rope, stick the end of the wire into the heart of the rope, whip it with twine, scrape the hemp into a point and serve it with twine. This stray line reaches from the winch to the water when the ship is light, so that when winding in it is not necessary to look over the taffrail till the hemp reaches the winch. Then the rope can be taken hold of and the lead hauled in by hand. The depth-recorder, or sounding-tube, is hitched on to the sinker.

CHAPTER XV.

THE MERCURIAL AND ANEROID BAROMETERS.

As many seamen are but imperfectly acquainted with the fundamental principles of the Mercurial and Aneroid Barometers, a short description will not be out of place.

The word Barometer is compounded of two Greek ones signifying weight and measure, and the instrument is used accordingly to measure the weight of the superincumbent atmosphere. From this knowledge, *coupled with other matters* which will be discussed in the next chapter, conclusions are arrived at with regard to coming changes in the weather. The atmosphere, or invisible air-ocean, extends for many miles above the earth's surface, becoming more and more rarified in proportion to its height. This latter has not yet been determined with any degree of precision, but in a very attenuated form it is believed by some to reach even to 300 miles. Beyond this is *luminiferous ether*—an extremely fine imponderable fluid, supposed to pervade all space.

Barometer—meaning of word

Height of our atmosphere.

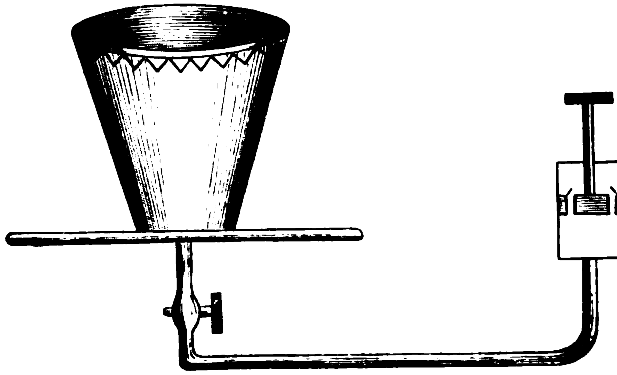
At the level of the sea the pressure on the atmosphere on every square inch of surface is about 15 lbs., or nearly one ton on the square foot, and is exerted equally in *all* directions—*upwards, downwards,* and *sideways.* Without actual proof, it is somewhat difficult to believe this from one's own sensations, but there are a hundred ways of shewing it. The most common method is as follows:

Pressure at sea level.

Let the mouth of an ordinary earthen flower-pot be tightly covered by a piece of bladder, well tied down round the neck. Stand it on the plate of an air-pump, so that the air inside can be exhausted through the hole in the bottom. When this is effected, the weight of the external atmosphere, being no longer counterbalanced by the previous *upward* pressure of the air within the pot, will cause the bladder to stretch and bulge inwards, and finally to burst with a loud report. In a small flower-pot, say of

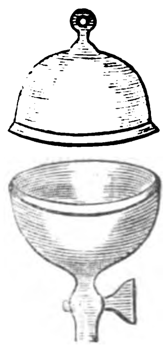
Experiment illustrating atmospheric pressure.

6 inches diameter, if a *complete* vacuum were formed (which, by the way, is impossible), the effect of the downward pressure on



the bladder—supposing it capable of withstanding it—would amount to over 400 pounds.

Magdeburg Hemispheres. The same thing may be demonstrated yet more clearly by means of what are known as the Magdeburg Hemispheres. They

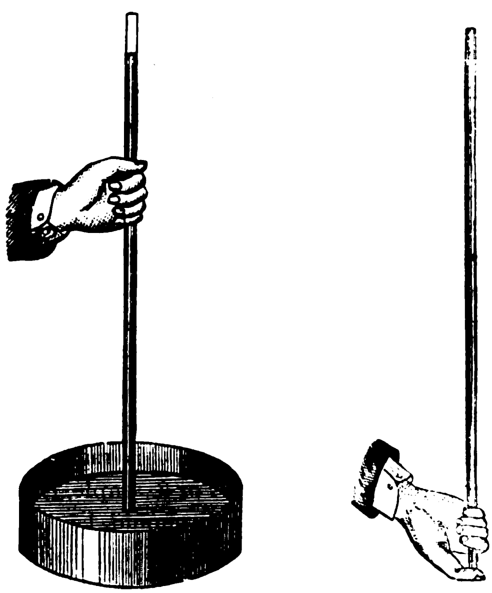


are two hollow cups, made to fit on to one another, with an air-tight joint. When pressed together by hand in the ordinary way, they are easily separated, there being, in fact, no appreciable resistance; but if connected with an air-pump, and a vacuum formed within the cups, so that the air is only allowed to exert its force on their *outer* side, it will be found very difficult to pull them asunder, the amount of strain required depending upon the sectional area of the circle: for instance, if the hemispheres should be 14 inches in diameter, they will, after exhaustion, be pressed together with a force of upwards of a ton, and as this is the case *in whatever position they may be held,* it proves that atmospheric pressure is exerted equally in *all* directions.

A familiar and not unpleasant example is afforded by sucking up sherry-cobbler through a straw. By drawing in the breath a vacuum is created in the straw, and the atmosphere pressing upon the liquid in the tumbler, forces it to rush unopposed into the vacant space.

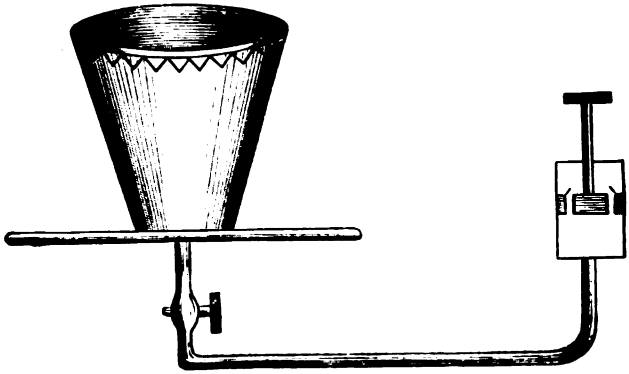
It is supposed that in the vortex of some cyclones the spirally ascending currents cause a partial vacuum, and it has been stated that during the passage of the *calm* centre of a West Indian hurricane, the windows have been forced *outwards* into the street by the greater pressure of the air *within* the houses. **Vortex of cyclones.**

The pressure of the atmosphere having thus been demonstrated, it merely remains to show its particular mode of action on the barometer. This can best be illustrated by the following simple and time-honoured experiment:—



Take a glass tube about 33 inches in length, hermetically sealed at one end. Fill this with pure mercury, and have some more handy in a small vessel, such as a teacup. Press the finger tightly over the open end to act as a stopper, and invert the tube, placing the end covered by the finger in the cup containing the mercury, and when well below the surface, remove the finger. The first assumption would be that *all* the mercury would instantly flow into the cup. Not so, however. The quicksilver will only fall in the tube—leaving a vacant space in the upper **Construction and principle of mercurial barometer**

6 inches diameter, if a *complete* vacuum were formed (which, by the way, is impossible), the effect of the downward pressure on



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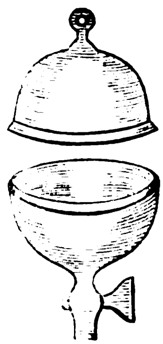

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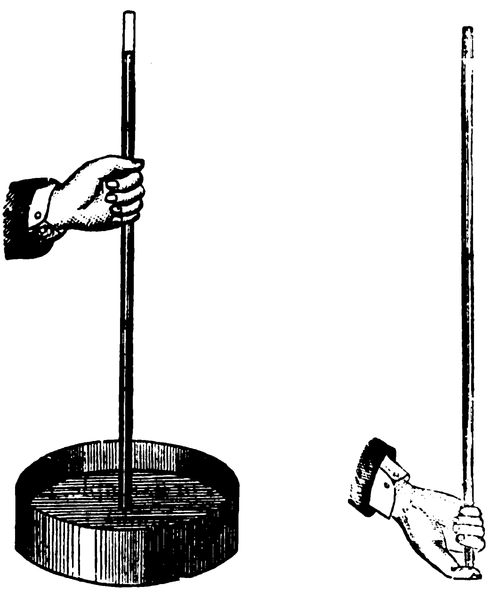

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How it weighs the atmosphere

To put this more plainly—supposing the glass tube to have an internal transverse area of exactly one square inch, and that the height of the column was ascertained to be 30 inches, this would give the contents as 30 cubic inches. Now, one cubic inch of mercury at a temperature of 60° (Fahrenheit) weighs ·491 of a pound, so that the total weight of the mercury in the tube would be equal to $30 \times \cdot491$, or 14·73 pounds, which would *also* be the weight of a column of the atmosphere indefinitely high, having a similar sectional area of one square inch. Air, even in small quantities, is capable of being weighed; with barometer at 30 ins., and thermometer at 62° Fahr., 100 cubic inches of dry air will weigh nearly 31 grains.

Thus we see that the barometer (true to its name) affords a very ready means of determining at any moment the weight or pressure of the atmosphere. This is in fact *all* it is capable of doing when only the reading at one place, as on board ship, can be obtained.

Torricellian vacuum.

The blank space left at the top of the tube by the descent of the mercury *is the nearest known approach to a perfect vacuum.*

Excepting some small details, it is in this manner mercurial barometers are actually constructed. For example, it is necessary that by means of a lamp the mercury should be boiled in the tube to free it thoroughly from air-bubbles. A suitable cistern is of course substituted for the tea-cup, and a scale of *inches* is affixed, whereby to read off the height of the mercury in the tube above the level of that in the cistern.

Scale reading—how named.

The reader will therefore understand that the mercury does not rise and fall in the tube merely by its own expansion, or contraction due to temperature, but that it is forced to rise, or suffered to fall, according to the varying pressure of the atmosphere; and that the scale readings represent *inches* and *decimal parts of an inch,* not *degrees and minutes,* as the writer has heard them referred to more than once.*

As stated at the commencement of this chapter, the atmospheric

* For a more modern but less known method of scale readings see p. 577.

pressure or density decreases according as we ascend above the sea-level, which latter is adopted as the datum-line for barometrical measurements. It does so in obedience to certain known laws which, it should be said, include considerations of temperature, and not infrequently we avail ourselves of this knowledge to measure the height of mountains by comparing the readings (taken simultaneously) of two barometers, one at the base or sea-level, and the other at the summit. Roughly, *for small elevations*, a vertical ascent of 900 feet corresponds to a fall of one inch in the height of the barometer. The depth of a mine may of course be measured in the same manner.

Mountain Heights.

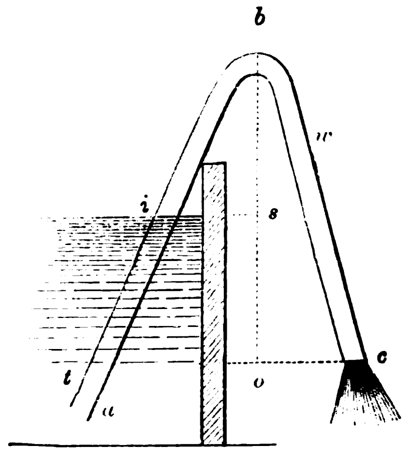
If water were used in a barometer instead of mercury, the tube would require to be about 36 feet in length. Water, being 13·6 times lighter than quicksilver, would be forced proportionately higher, and when the mercurial column stood at 30 inches, the water column would have a height of very nearly 34 feet. It is due to this fact that we are able with a common two-valve suction pump to lift water out of a well from a depth of about 28 or 30 feet.

Water Barometer

The action of a siphon is another instance of atmospheric pressure turned to account in a very ingenious way. The siphon is used to draw off liquids from vessels which it is not convenient or desirable to move, and with care it can be arranged to do this without disturbing sediment at the bottom—sometimes a matter of great importance. A vacuum being first formed in the tube, the liquid enters the immersed leg and fills the place of the exhausted air; and since the pressure on the orifices of the tube is in each case equal to the weight of the atmosphere, *minus the height of the liquid in the respective legs*, it follows that the greater the difference of level between the surface of the liquid to be withdrawn and the orifice of the leg by which it issues, the more rapid will be the flow; and further, that a siphon will cease to act if the height from the surface of the liquid to the bend of the pipe be greater than that of a column of the liquid in use sufficient to counterbalance the atmospheric pressure: consequently, if we were seeking to remove *water* from a vessel by means of a siphon, the difference in height between the bend of the pipe and the surface of the water must be less than 34 feet, and in the case of *mercury* it would require to be under 30 inches.

How the Siphon acts.

The following diagram and explanation ought to make the matter clear.



"If one leg *ab* of a bent tube or pipe *abc*, of any diameter, filled with water, and with both its ends stopped, be placed in a reservoir of water, and if the stoppers be then removed, the water in the reservoir will begin to flow out at *c*, and will continue to do so until its level is reduced to *t*, which is the same as that of the *highest* end *c* of the pipe or siphon. The flow will then stop. The parts *ab* and *bc* are called the legs of the siphon, *b* being its highest point; and this is correct so far as relates to it merely as a piece of tube; but considering it purely with regard to its character as a hydraulic machine, the part *ta* below the level of the higher end *c*, may be entirely neglected; for the water in the reservoir will not be drawn down below the level of the higher end, whether that be the inner or the outer one. Therefore, if the discharge end be above the surface of the water in the reservoir, as for instance at *w*, no flow will take place.

"The vertical height *bo*, from the highest part of the siphon to the lowest level *t*, to which the reservoir is to be drawn down, must not, theoretically, exceed about 33 or 34 feet, or that at which the pressure of the air will sustain a column of water. Practically it must be less, to allow for the friction of the flowing water, and for the air which forces its way in: and still less at places far above sea level, for at such the reduced weight of the atmospheric column will not balance so great a height of water.

"In order readily to understand, or at any time to recall the principle on which the siphon acts, bear in mind that we may theoretically consider the end of the inner leg to be not actually immersed *below* the water surface, but only to be kept precisely *at* it as the surface descends while the water is flowing out; but may regard the vertical distance *bo* as the length of the outer leg; and a varying distance, which at first is *bs*, and finally *bo* (as the surface of the water descends) as the length of the inner leg; and that the flow continues only while *this* outer leg is longer than *this* inner one. The books are wrong which say that the outer leg *bc must* be longer than the inner one *ba*, in order that the water may run at all. The principle then is simply this: that both these legs *bc* and *bi* being first filled with water (the part *ia* being considered at first as a portion of the *reservoir*, and not of the siphon), it follows that when the stoppers are removed from the orifices *c* and *a*, the air presses equally against these orifices; but the great vertical head of water *bo* in the outer leg *bc*, presses against the air at *c* with more force than the small head of water *bs* in the inner leg *bi* does against the air at *a* or *i*; consequently the water in *bc* will tend to fall out more rapidly than that in *bi*, and as it commences to fall would produce a vacuum at *b* were it not that the pressure of the air against the other end *a* or *i* forces the water up *ib* to supply the place of that which flows out at *c*. In this manner the flow continues until the surface of the water in the reservoir descends to *t* on the same level as *c*. The pressure of the vertical heads *bo*, *bo*, in the two legs *bc*, *bt*, being then equal, it ceases."

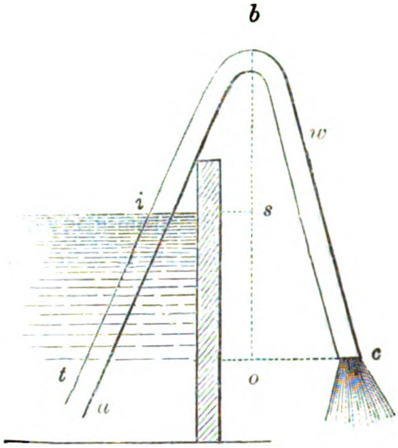
It may be added that, to entirely drain the reservoir, the outer leg would require to be longer than the inner one.

For many reasons a water barometer is unserviceable for scientific purposes, but experiments, attended with a certain amount of success, are being tried with glycerine as a substitute. Mercurial barometers are not most in demand for use on board ship, being superseded by the handier *and more sensitive* Aneroid. **Water Barometer**

It is often difficult to find a suitable spot for the mercurial barometer in the confined cabins of vessels. They are apt to be knocked against and broken. To avoid this, it is not uncommon to see them suspended inside the skylight—the worst possible place. To indicate truly, the sun must not shine on the instrument, nor should it be exposed to currents of air, as is almost certain to happen in such a situation, and in which, moreover, it is not as accessible as it ought to be. Again, should a chance sea break the skylight, the barometer will also come to grief. **Precautions necessary with mercurial barometer.**

Unless the instrument hangs truly vertical, the level of the mercury within the tube will be *too high*. For this reason, therefore, when the ship is rolling, it must on no account be steadied or held in the hand whilst being read off. If anything, such as spiral springs or elastic bands, interfere with its free movement, the readings will be erroneous.

We next come to the Aneroid. This word is derived from three Greek ones, signifying "not of the fluid form," or "without moisture." Where observations are not required for strictly scientific purposes, it is a convenient instrument for use afloat. It is more portable, and occupies much less room; for example, it may be kept in a drawer, on a shelf, or fastened to a panel near one's bed, so as to be visible without effort. As already stated, it is more sensitive than the mercurial barometer, and at all times—more especially in heavy weather—easier to read. **Portability** **Sensitiveness**



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In the Aneroid, fluctuations of the atmosphere are measured by its varying pressure on an elastic metallic box, from which almost all the air has been withdrawn, and which is kept from complete collapse by a strong spring. The exterior of this vacuum chamber, as it might be called, is so connected by multiplying levers and springs with the pointer which traverses the face of the instrument, that the slightest increase or diminution of pressure is at once unmistakably indicated.

From the perfection of make arrived at, and its great portability, the Aneroid has been very commonly used in the determination of mountain heights; also by engineers for contouring, and roughly ascertaining differences of level in a hilly country, when running what are termed "trial lines" as a preliminary to a close survey for a new railway. For these purposes the face of the instrument is graduated on both an inner and outer circle, the one corresponding to inches of mercury, and the other to so many feet of elevation. Taking 30 inches as zero, a reading of 18 inches would correspond to an elevation of close upon 14,000 feet. Mr. E. Whymper, of mountain-climbing celebrity—during his travels amongst the Great Andes of the Equator—made exhaustive investigations which, combined with his subsequent workshop experiments, prove conclusively that for height-measuring at great altitudes the Aneroid is very unreliable, and that invariably it gives the height greater than it really is. He also found that, on being quickly subjected to considerable difference of pressure, its first indications were very different to those obtained a few weeks later, though the pressure to which it was last submitted had not changed in the interval. To use Mr. Whymper's expression, a "state of repose" is not arrived at by the instrument for quite a long period—perhaps months. It remains to be seen whether some clever mechanician can overcome this defect; Mr. Whymper is sanguine that, at all events, it can be diminished: meanwhile, the Aneroid is the easier instrument for use on board ship. The Aneroid, however, has a nasty knack of varying its index error, and must be frequently compared with a standard mercurial barometer.

Defective as a height-measurer.

Occasional comparison with Standard desirable.

As the delicate mechanical parts are liable to suffer from rust, wear and tear, and other causes, it should, as a precaution, be occasionally compared with a standard mercurial barometer.

Mode of adjustment.

It is just as well that seamen should know that the Aneroid can at any time be easily adjusted to a higher or lower reading by a deep-set screw at the back. By *carefully* turning this screw to the right or left with a bradawl, the pointer can be moved in the required direction. Before setting a *compensated* Aneroid by a standard mercurial barometer, the reading of the latter should be corrected for temperature by the table for this purpose.*

A full description of the Aneroid, with illustration, is given in Allingham's *Manual of Marine Meteorology.*

*

Temperature of thermometer attached to mercurial barometer.	40°	50°	60°	70°	80°	90°
Correction to be applied to reading of mercurial barometer.	– ·03	– ·06	– ·08	– ·11	– ·14	– ·16

The comparison should be made with the Aneroid in two positions, one in the upright position, or as it would be when suspended; and the other on its flat, as it would be when lying on a table. In nearly every instance there is a difference. Should the mercurial barometer have an index error, as often happens, the proper correction therefor must also be applied to its reading before that of the Aneroid made at the same instant is compared with it. *Example.* An Aneroid reads 30·05, as against 30·00 shown by a mercurial barometer which is known to be ·02 too low throughout the scale, and the temperature indicated by the thermometer attached to the mercurial barometer is 85°. A reference to the above table shows that at 85° the correction for temperature is —·15; and the index error is + ·02; hence the correction to be applied to the reading of this mercurial barometer is (—·15 + ·02) = —·13, and the corrected reading is 29 87. Therefore the pointer of the Aneroid requires to be moved to 29 87. Since the mercurial and the Aneroid are assumed to be at the same height above sea level it is unnecessary to apply any correction for height. In comparing a ship's barometer, whether mercurial or Aneroid, with a shore reading—which is corrected for temperature, height above sea level, and index error, as a rule—the correction for height above sea level will have to be made at the rate of +·01 for each ten feet. Having regard to modern docks a grave difficulty crops up occasionally in determining the height above sea level. It may, or may not, be the same as the height of the barometer cistern above the level of the water in the dock, or the canal, in which the ship happens to be at the time. The mercurial column in a barometer rises and falls, after the manner of a thermometer, as the temperature varies; and the pressure of the atmosphere decreases, as we go aloft. Hence the necessity to correct readings from such a barometer to what they would be if taken at 32° F.; and also reduce them to what they would have been if taken at sea level; in order that they may be comparable *inter se.* In noting the barometer readings in the ship's logbook, or on forms for shore offices, the entries should be made without any corrections whatsoever having been applied. A statement of the kind of barometer in use; the height of the instrument above sea-level; and its index-error, should be forwarded with the records, when possible.

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Temperature of thermometer attached to mercurial barometer.	40°	50°	60°	70°	80°	90°
Correction to be applied to reading of mercurial barometer.	-·03	-·06	-·08	-·11	-·14	-·16

The comparison should be made with the Aneroid in two positions, one in the upright position, or as it would be when suspended; and the other on its flat, as it would be when lying on a table. In nearly every instance there is a difference. Should the mercurial barometer have an index error, as often happens, the proper correction therefor must also be applied to its reading before that of the Aneroid made at the same instant is compared with it. *Example.* An Aneroid reads 30·05, as against 30·00 shown by a mercurial barometer which is known to be ·02 too low throughout the scale, and the temperature indicated by the thermometer attached to the mercurial barometer is 85°. A reference to the above table shows that at 85° the correction for temperature is —·15; and the index error is + ·02; hence the correction to be applied to the reading of this mercurial barometer is (—·15 + ·02) = —·13, and the corrected reading is 29 87. Therefore the pointer of the Aneroid requires to be moved to 29 87. Since the mercurial and the Aneroid are assumed to be at the same height above sea level it is unnecessary to apply any correction for height. In comparing a ship's barometer, whether mercurial or Aneroid, with a shore reading—which is corrected for temperature, height above sea level, and index error, as a rule—the correction for height above sea level will have to be made at the rate of +·01 for each ten feet. Having regard to modern docks a grave difficulty crops up occasionally in determining the height above sea level. It may, or may not, be the same as the height of the barometer cistern above the level of the water in the dock, or the canal, in which the ship happens to be at the time. The mercurial column in a barometer rises and falls, after the manner of a thermometer, as the temperature varies; and the pressure of the atmosphere decreases, as we go aloft. Hence the necessity to correct readings from such a barometer to what they would be if taken at 32° F.; and also reduce them to what they would have been if taken at sea level; in order that they may be comparable *inter se.* In noting the barometer readings in the ship's logbook, or on forms for shore offices, the entries should be made without any corrections whatsoever having been applied. A statement of the kind of barometer in use; the height of the instrument above sea-level; and its index-error, should be forwarded with the records, when possible.

CHAPTER XVI.

OCEAN METEOROLOGY.

"The most difficult problem of Astronomy becomes simplicity itself when compared with the extraordinarily complex agents that are in operation even with the simplest meteorological phenomena."—SIR ROBERT BALL, *Royal Astronomer of Ireland.*

Meteorology and Astronomy.

Undoubtedly in the days of long ago Astronomy was in much the same precarious position as Meteorology is to-day; but just as a Kepler and a Newton evolved order out of chaos in Astronomy, so we are justified in expecting the advent of mathematical precision for Meteorology.

If hopes were dupes, fears may be liars;
It may be, in yon smoke concealed,
Your comrades chase e'en now the fliers,
And, but for you, possess the field.—*Clough.*

The wood not to be seen for the trees.

Since the days of Fitzroy, the Unselfish, who was among the first in the United Kingdom to set the ball rolling, Meteorology, as a subject of general interest, has received a vast amount of attention from all sorts and conditions of men. Quite an army of co-operators, unpaid and paid, both afloat and ashore, have observed and noted down meteorological observations at regular intervals daily with varying degrees of exactitude. These valuable records have been forwarded from time to time to the world's Meteorological or Hydrographical Offices; and the results of the detailed discussions thereof, incorporated in official publications, have been published for the benefit of seafarers and others. The shelves of Weather Offices groan with undiscussed observations, yet the cry is still they come; and it is very difficult, if not altogether impossible, to formulate a plan which shall prevent such a regrettable accumulation of data without the remedy proving worse than the disease.

Dangerous dogmatism.

Though slow to advance, and inexact in a great measure, Meteorology has evinced a tendency towards greater certainty since *Wrinkles* first appeared; and this, more especially, in that portion which is of the utmost importance to the seaman. Points which were doubtful have been more nearly determined; some vaunted theories have proved full of fallacies, while other theories are now generally accepted; and, altogether, the world is not so hopelessly involved in a meteorological maze as appeared to be the case when the late Admiral Fitzroy was entrusted with the foundation and the conduct of a British Meteorological Office.

Laws once dogmatically put forward by shore-dwellers, in opposition to the competent conclusions of intelligent and experienced seafarers, have been demonstrated to be but partially true, to require much modification, and to have many unsatisfactory links in the chain of proof and of argument. This is similar to the experience of pioneers in every branch of science, but incomplete deductions have to serve until something more reliable is given in lieu. The earlier writers on the laws of storms—such as Capper, Piddington, Redfield, Reid, and Thom—made some erroneous inferences from the scanty data at their command, as might be expected; but they are entitled to all honour and respect for the zeal and capacity with which they undertook such an arduous task, as the amount to unlearn was perhaps greater than the amount to learn. Paste-pot and scissors have ever been to the fore in Meteorology; originality in method is sometimes regarded with disfavour; and scarcely any improvement has been made by more modern men on the system of discussion adopted by Piddington and Redfield, although the books of those early writers on the laws of storms have necessarily become almost obsolete owing to the efflux of time.

Pioneer zeal.

The reader, however, must not jump to the conclusion that we have arrived at the summit of meteorological knowledge, and that henceforth all will be plain sailing. There is still plenty of scope for inquiry over the Pacific Ocean, the South Atlantic, the Indian Ocean, the Bay of Bengal, and the Arabian Sea; but the beaten track is not by any means that which will lead to reliable results, if any. Many will agree with Sir Robert Ball as to the numerous variables in the complex problem of Meteorology; yet, curiously enough, many a shore-dweller of merely meagre capacity poses as a born meteorologist. Astronomers, Chemists, Electricians, Engineers, and others who combine theory with practice, have brought their several branches of science to that satisfactory stage where almost all of the facts are expressed in mathematical formulæ, easy of demonstration or otherwise; but, thus far, the weather has defied every attempt to reduce its laws to algebraical expressions, although thousands of precisely similar series of circumstances must have been placed on record since the invention of the barometer and the thermometer. The unknown quantities are so numerous and so seldom regarded, the known are so little understood, that it is next to impossible to say exactly the kind of weather which will follow any particular change in the atmospheric conditions. Too often the scaffolding used for construction is confounded with the meteorological ship herself; or, to put it in more popular terms, the wood cannot be seen for the trees. Taking the weather of the British Isles, by way of example, it is only within the past thirty years, consequent on the spread of telegraphic communication and a carefully organized system of reports made from all parts of Europe to a central office in London, that it has become possible to keep a close watch on the progress of weather changes in

Plenty of room on the top.

Weather Telegraphy.

the vicinity. Without telegraphy weather forecasting would be but a name! Daily weather charts are now familiar to most people; and from a study of similar charts, embracing a large oceanic area to the westward of Ireland, it has been proved that the weather of Western Europe is principally dependent upon travelling atmospheric disturbances which reach the coasts of the United Kingdom after having passed eastward over the Atlantic for some distance.

United Kingdom Storm Warnings.

Our home-trade seamen are more especially interested in British weather, although deep-water vessels when making or leaving the land are equally concerned; but, to master its subtleties, an intimate knowledge is necessary of the atmospheric conditions which prevail over the Atlantic to the westward, the circumstances leading up to the birth of a storm, and the ways in which the various weather systems act each on the other. The first of these, owing to the lack of outlying islands between Ireland and Newfoundland, for many years appeared to be impossible of attainment. Of recent years wireless telegraphy has become an accomplished fact; and it has evidently come to stay, because quite a number of large steamships are now fitted with the necessary apparatus which enables them to keep in commuication with the shore or with passing ships possessing similar apparatus. The utility of this system is, however, limted to a certain radius, and it remains for Marconi, or some other genius, to devise a plan whereby wireless telegraphy will keep seamen on the coasts of the world in close touch with the weather conditions along the route they wish to follow. A storm warning from a shore station is far from commendable, consequent on local conditions, and it is indispensable that it be both seamanlike and certain.

Storm Warnings from the United States.

A few years ago our near kindred on the other side of the North Atlantic, under the auspices of the *New York Herald*, used obligingly to cable across to the United Kingdom the departure of storms travelling eastward towards our shores. The results clearly indicated that, after a cyclonic storm had left the continent of North America, not even those posing as experts could predict with any degree of accuracy worth mentioning just what would happen to the meteor. Sometimes the system would diverge inexplicably to the north, sometimes to the south, of the path predicted for it; sometimes it seemed to disappear entirely in mid-ocean; sometimes its progress was retarded and again accelerated; and when one did manage to fetch across, it was either some hours ahead of time or as many hours behind time. Occasionally storms left the United States full of fury and bent on mischief, but something intervened during the passage and they reached our shores harmless enough; and at other times the meteor of little importance on the east coast of North America developed energy—as the cant phrase goes—on the trip across, and the force of the wind attained to almost that of a hurricane by the time the English Channel was reached. Lastly, storms were sometimes generated in mid-ocean, remote from the New World as from the Old, and of these the Americans had not the least knowledge. The *New York Herald* weather predictions were theoretically praiseworthy, but were ahead of their time, and they proved most unreliable. Inasmuch as modern weather forecasting is but weather telegraphy writ large, and having due regard to the fact that wireless telegraphy is becoming more and more common at sea between large liners themselves and with shore stations, the near future may find a modified *New York Herald* system quite satisfactory. The British Meteorological Office essayed the task of testing the *New York Herald* storm warnings, did not discover much agreement between the predictions and the actual experience, and decided to ignore them altogether as misleading. "Under any circumstances," says the report, "in the present state of our knowledge, the aid derived from such trans-Atlantic messages must be very slight, and at times the knowledge that a deep depression had left the United States had caused the premature issue of warnings to our coasts, and a consequent failure, which would otherwise have been avoided." It might logically be urged, however, that a competent weather forecaster, who is presumably familiar with every type of weather and its antecedent conditions, ought not to be induced to act like a tyro by the sight of a scare headline. Cable advices of the weather sent from the United States are not likely to be of much use in forecasting United Kingdom weather, unless backed up by wireless messages from ships in telegraphic touch from shore to shore; and this conclusion is fully sustained by a careful study of a long series of synchronous weather charts of the North Atlantic, which give a graphic representation of matters meteorological prevailing over the whole oceanic area at Greenwich Mean Noon—after the event, of course.

Wireless Telegraphy

So far back as 1847, Redfield seems to have suggested the use of the electric telegraph in weather forecasting; but the late Admiral Fitzroy may rightly be looked upon as the pioneer of this utilitarian branch of science, based upon actual observations transmitted by telegraph from remote stations to a central weather office, to be discussed there and the information issued to the seaports (as regards storms) when deemed necessary. Americans are most favourably situated for weather prediction, inasmuch as the majority of their storms originate near the "Rockies," travel eastward over many a league of territory, and are, therefore, amenable to telegraphic forecasting well in advance. It is quite another matter when storms say good-bye to the land of their birth, and are shot off on an ocean trajectory of three thousand miles. The gunner's aim may be bad, or the powder may be either damp or too dry; result, more harm than good to those on this side who hoped to profit by the prediction.

Failure of long range weather forecasts.

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Failure of long range weather forecasts.

In 1871 the Anglo-American Telegraph Company brought to a conclusion a system of weather messages sent to England from Heart's Content, Newfoundland, which had proved unsatisfactory for various reasons, local and otherwise. H.M.S. *Brisk* was anchored for six weeks in 1869 at the mouth of the English Channel as a storm-warning vessel; but this very costly attempt was perforce abandoned because, as was alleged, the experimenters were unable to maintain the telegraphic connection in working order. Captain W. Parker Snow once suggested a trans-Atlantic cordon of ships, moored in some way at intervals of 500 miles, which should be in electrical communication with each other and with the land at either end of the system. Morse, of telegraph fame, went even further than this flight of a perfervid imagination. He proposed that buoys, fitted with electrically self-registering apparatus, should be substituted for ships and their expatriated crews; and, by this means, the record of matters meteorological would be registered automatically at the nearest station on land coupled up with the buoys, anchored at short intervals all along the great ocean highway which divides, yet unites, the United States and the United Kingdom.

The British Meteorological Office has very many special meteorological log-books on its shelves which were kept on board vessels in the Atlantic by officers and masters in close co-operation, and a critical overhauling thereof by a nautical expert "would perchance determine whether, and how often, a *Campania*, or a *Paris*, might give reliable storm warnings at either end of the journey, provided every effort were made to obtain such information immediately upon arrival at Queenstown, Southampton, and New York."* Much has happened since 1894—thanks to Marconi, De Forest, and electricians of like calibre. The London *Daily Telegraph* for some time published information of this nature, obtained from the fast steamers arriving within wireless striking distance of the United Kingdom shore stations; but this new departure was not an unqualified success owing to limits imposed by the apparatus, and was abandoned in August, 1906.

Prior to the advent of Redfield (a naval architect of New York) and Piddington (an English seaman), accuracy was denied to the laws of storms. Probably the first hurricane on record is that experienced by the caravels of Christopher Columbus, not far from the Azores, in February, 1493. In 1698, a British merchant shipmaster named Langford called attention to the close relationship between a West India hurricane and a whirlwind, and pointed out that warnings of storms sent to the more western islands from Dominica and St. Vincent were not in-

* *Forecasting of Ocean Storms, and the best methods of making such Forecasts available to Commerce.* By WILLIAM ALLINGHAM. Report of the International Meteorological Congress. Washington, D.C., Weather Bureau. 1894.

frequently justified by subsequent weather. He used to get underway and run out before the northerly gale in anticipation of a shift to the south-west, which wind would bring his vessel back to port. Over three hundred years ago seafarers had grasped the main facts underlying the laws of storms, but the electric telegraph and State-supported meteorological offices were then far below the horizon of progress. In July, 1687, one of England's sterling seaman, William Dampier, had fully recognised that the hurricanes of the West Indies and the typhoons of the Far East are very nearly related. "For my part," wrote that old sea-dog of pleasant memory, "I know no difference between a Hurricane among the Caribee Islands in the West Indies and a Tuffoon on the coast of China or in the East Indies, but only the name." In July, 1747, Benjamin Franklin, patriot and philosopher, pointed out that "the air is in violent motion in Virginia before it moves to Connecticut, and in Connecticut before it moves at Cape Sable." As ships increased in numbers, and more reliable instruments came into use on board of them, the paths of inquirers into matters pertaining to ocean meteorology became less difficult to follow; but it was reserved for W. C. Redfield, of New York, in 1831, to demonstrate much that had hitherto rested upon assumption, and to dispose of much that was erroneous. Modern weather-workers have adhered slavishly to his method of inquiry, as a rule; and, as a consequence perhaps, the laws of storms are almost precisely as they were handed to posterity by Redfield and Piddington. They collated information from ships' log-books with respect to the subject under discussion, and laid down the data in geographical position on large daily charts by the aid of suitable symbols. Redfield devoted his attention more especially to cyclonic storms of the North Atlantic, while Piddington did the same for the Indian Ocean. To Piddington we owe the expressive term cyclone as applied to revolving storms, which he derived from the general significance of the Greek word κύκλοι, as inclusive of any closed curve.

Old time Cyclonology

Since the days of Redfield and Piddington the system of oceanic weather discussion through the intermediary of synchronous charts has often been followed in the United Kingdom and elsewhere; although, in so far as the Atlantic is concerned, nothing new and true has been added thereby to the world's knowledge of matters meteorological. In 1882 the then Meteorological Council of the Royal Society, which controlled the destinies of the British Meteorological Office, determined upon a series of synchronous charts of the North Atlantic to cover the whole thirteen months, day by day, from 1st August, 1882, to 31st August, 1883, on a scale never hitherto possible. To Lieutenant Weyprecht of the Austrian Service is doubtless due the conception of this vast undertaking of an international nature embracing a considerable number of circumpolar stations

Synchronous Charts.

at that time available. The English authorities appealed to the commanders of ships for the necessary particulars on specially prepared forms supplied by the Meteorological Office; a nautical expert was detached to visit ships at London and Liverpool, together with the principal shipping offices at both ports; and the response was all that could be desired, along the beaten tracks, even by the most optimistic. Data were obtained from 3,000 ships, on 11,236 forms, or 864 for each of the thirteen months of the period, thus giving an average of more than 400 observations daily from ships of all nations in the North Atlantic. Land stations on both sides of the oceanic area were also pressed into the service to the number of about 300 each day. Hence, in the preparation of the "Synchronous Weather Charts of the North Atlantic and Adjacent Continents," afterwards published by the London Meteorological Office, not fewer than 700 sets of meteorological synchronous observations were dealt with on the chart for each day. Among the land stations there were quite a number in high northern latitudes; and the nautical expert having confined his efforts to ships of every nation, especially sailing vessels, other than the regular liners between the United States and the United Kingdom, the observations south of that beaten track were well represented. Hence it follows that the weather conditions represented on those charts should convey a far more accurate idea than anything of the kind attempted before or since based almost solely upon observations obtained from ships traversing the North Atlantic between the 30th and 50th parallels of North Latitude.

Sympathetic Co-operation of Nautical Observers.

A huge Ocean Weather Discussion.

A very violent storm having crossed the British Isles on September 1st to 3rd, 1883, these three days were added to the period originally chosen; so that the series comprised 399 days' charts representing the state of the weather at Noon, Greenwich Mean Time, each day, over an area extending from the Equator to the Polar Regions, and from the Pacific Coast of North America to the eastern confines of Europe. The labour of reducing the observations and compiling the charts can be but imperfectly imagined. Not one-third of the amount of data utilised in this series had been available for any previous discussion of a like nature. Numbers, however, are a very misleading test as regards synchronous charts, inasmuch as where several ships are in company, or even in close proximity, they are not of any more value than one reliable observation. Hence it is matter for congratulation that both to the north and to the south of the zone frequented by shipping the total number of observations available from ships at sea was decidedly in excess of the average.

Intermediate change in Atlantic weather conditions.

To confuse the issue as little as possible, the meteorological conditions of each day were represented on two adjacent charts. On one were set forth the distribution of atmospheric pressure as evidenced by the readings of the barometer, the direction and force of the wind, and the state of the weather; while on the other were given the temperature of the air in the shade and also the temperature of the sea surface. It matters not where this series of meteorological charts is opened, the same feature of ceaseless activity and incessant change is apparent; for not any two days are exactly alike. Isobars, or lines of equal barometic pressure, are drawn through the geographical positions on the charts at which the barometer reading in the vicinity are the same, just as the 100 fathom line of soundings is drawn through all places where that depth is obtainable near a coast; and the resulting cyclonic and anti-cyclonic systems of low and high barometer readings not only are of different shapes and sizes on any given chart, but also vary from day to day. It is to this interminable change that is due the fickle nature of the weather so characteristic of the United Kingdom. Every variation in form, or in energy; every alteration in the direction, or in the rate, of translation is undoubtedly regulated by some definite law of Nature; and this, although at a cursory glance it would seem almost impossible to reduce to any order worth mentioning the bewildering medley of events thrown together of necessity on a synchronous chart. The exercise of a certain amount of patience on the part of an unbiassed inquirer, however, will bring to light the fact that in weather, as in other sublunary matters, Nature's first law is most pronounced. Prior to Kepler and Newton, Astronomy was in as unsatisfactory a state as Meteorology is to-day; and for a similar reason. Means are confounded with ends; and initiative is wanting. Experience in meteorology is too often on a par with the stern light of a ship which only illuminates the track overpassed, and Procrustean principles are fatal to advance. Without a daily bird's eye view of the whole of the surrounding weather conditions it is difficult to form even an approximate estimate of the influences at work; but, unless the imagination of the weather worker be duly restrained, such bird's eye views, in the form of synchronous charts, may mislead the seeker after truth. What a celebrated French critic once remarked about virtue is as applicable to the use of the imagination in the drawing of isobars: "*Il en faut; mais il n'en faut pas trop.*" This precept is too often either forgotten or ignored; so that a synchronous chart may be a help, but it may be a hindrance.

A Meteorologic Kepler required.

In a cyclonic system, the winds revolve around an area of comparatively low atmospheric pressure in either hemisphere, so that the westerly wind is always on the side nearest the Equator; and it must not be forgotten that the wind force in such a system is not necessarily that of a gale. In an anti-cyclonic system the wind revolves around an area of comparatively high atmospheric pressure in either hemisphere,

Wind motion in a Cyclone.

so that the easterly wind is always nearest to the Equator; and it is well to remember that the winds of an anti-cyclone are not always of a light force. The force of the wind does not depend upon the absolute height of the mercury in the barometer, but upon the relative height at places not far remote from each other. A cyclone is not an isolated phenomenon, but is merely an "episode" in the general circulation of the atmosphere. Cyclones and anti-cyclones exist in close proximity, and each is dependent in a measure upon the other, for "Nature abhors a vacuum." Descending currents from the regions of highest barometer are drawn into the neighbouring regions of lowest barometer, where they ascend into the upper regions of the atmosphere, and are again transferred to the anti-cyclones, thus effecting a continuous interchange. Curiously enough, it would appear as though seafarers, through all the ages of sail and steam, have not experienced an appreciable updraught of wind while under the influence of a cyclonic storm, nor a downdraught in an anti-cyclone.

Where is the Updraught?

Unsatisfactory Angles of Indraught.

The question of the indraught of the wind in a cyclonic system has received much attention by the earlier writers on the laws of storms. Some affirmed that a cyclonic storm is a huge circular whirl with its wind particles proceeding along purely circular orbits; some were just as strongly of opinion that the wind worked towards the centre along equi-angular spiral paths. Neither Redfield nor Piddington, however, regarded the whirl as perfectly circular, although the diagram approximating to a geometrical circle was rightly deemed by them as of sufficient preciseness for practical purposes at sea, where undue refinement is to be deprecated. One thing is certain! Owing to the fact that a ship is not a fixed observatory, and that the determination of wind force on a steamship is far from easy, confusion can only result from efforts to arrive at a measure of the angle of indraught by means of observations taken on board ships under the influence of a hurricane when there are other matters to be safeguarded. On the other hand, wind direction at shore stations is subject to adverse local influences, and this may introduce a serious error into the problem. The late Mr. Clement Ley found that five inland stations gave an average angle of indraught of 29°, while five on the sea coast gave an average of only 13°; but the individual records varied between 10° and 45°. Professor Loomis obtained an average indraught of 47° for United States winds, though this may be explainable by his inclusion of a number of instances of insignificant wind-force. According to theory, winds on the outer edge of a cyclonic system have a greater angle of indraught than those nearer the centre; and, again, just the converse of this has been deduced from a consideration of the wind arrows laid down in geographical position on large synchronous working charts. Hurricanes in low latitudes are

Premature Generalisations.

of small radius and great intensity; an unknown sea-surface current and lack of ship's position by observation are quite common on such occasions; and, consequently, conclusions based on such uncertain data are worse than useless — they are misleading.

Centripetal Suggestions

Espy, of the United States, considered that the wind blew from all quarters alike towards a common centre; and he attributed this centripetal travel to a supposed *upward* rushing of the air in the vortex—or core, to use the slang of the day —of the storm. Had such an upward trend been in evidence surely it would have been recorded by a proportion of the infinite number of seamen who have experienced West India hurricanes since the days of Christopher Columbus! On the outer verge of a cyclone the glass indicates high barometic pressure, and the barometer readings continue to fall as the dreaded centre is approached; and it might, therefore, be assumed that under these conditions the outer and heavily pressed air will move along the path of least resistance towards the imperfect vacuum at the centre. So far, however, practical proof is wanting! It is pretty well established that in some tropical cyclones the wind at some parts of the whirl not infrequently moves around the circumference of a true circle. On the other hand, the late Dr. Meldrum, when Director of the Government Observatory at Mauritius, who had unusually good opportunities of hobnobbing with cyclonic storms of the South Indian Ocean, considered that the north-eastely and easterly winds of those particular meteors often, if not invariably, blow directly towards the centre of the storm, instead of at right angles to the bearing thereof, as required by the purely circular theory.

Hurricane on verge of Trade Winds.

When a hurricane is moving along the equatorial range of a trade-wind region there is a belt of intensified trade wind on the windward side of the storm track. Should the trade wind increase to gale force, and remain steady in direction, it is not safe to assume that the vessel is directly in front of an advancing storm until the barometer has fallen at least six-tenths of an inch. Sometimes it would appear as though the circular theory is borne out by the records, and at other times it would seem that Espy's idea, although not quite right, was not absolutely erroneous. As a very eminent authority said in April, 1906, it is possible to prove diametrically opposite propositions by reference to a series of synchronous meteorological charts. This may be due, in a measure, to the vice inherent in the system itself; and many of the apparent irregularities in storm motion and storm life are undoubtedly due to either paucity of observations, erroneous observations, or a perfervid imagination on the part of the person who draws the isobars. With a distance of 600 miles represented by an inch on the working chart there is always a temptation to overstep the limit imposed by the environment upon the draughtsman.

Flaws in Synchronous System.

Incurvature of wind.

But more frequently than otherwise the direction of the wind is compounded of both the foregoing; and such a resultant of forces agrees with the spirally incurving movement accepted at the present time as the *general*, but not invariable, behaviour of the wind in cyclones. The incurvature is usually about two points, thus making the centre bear about ten points from the direction of the wind; but no positive rule can be laid down for this.

General loose behaviour of storms.

Storm areas are found to be of every variety of shape—circular, oval, elongated, and irregular; the same system may even alter its shape from day to day. Again, it is common enough for a cyclone to break up into two or more, each perhaps more violent than the parent system. The reverse of this also takes place; two or three low-pressure areas approaching from different directions become one, then some days later burst into a number of distinct cyclones again.

Again, one or more secondary disturbances sometimes hang about on the skirts of the larger ones: these may come into collision, and confusion reign supreme until the one will have merged into the other, the less being absorbed by the greater.

The sailor's dilemma.

These sudden changes, which cannot be foreseen, and the shapes of storms being so very different, introduce complications which would bewilder even a "Philadelphia lawyer." How then can the sailor, cut off as he is from all outside sources of information, calculate with Board of Trade precision the position of the dreaded centre? *As a fact, no rule is possible for determining more than approximately the position of the vortex of a cyclone by observations confined to a single ship.*

A case in point, illustrating the difficulty of applying the circular theory with a certainty of being right, is afforded by the great storm which prevailed off the Atlantic coast of the United States during the 11-14th March, 1888. This storm—of the "Blizzard" type—was sadly destructive, and will long remain a memorable instance of marked divergence from the circular theory. Charts compiled for each day of its continuance shew its path, intensity, and development. The main feature exhibited was an *elongated* area of low barometer, extending from the west coast of Florida up past the eastern shores of Lake Huron, and far northward towards Hudson Bay. On the western side of this stretch of low barometer the difference of pressure (or gradient) was very considerable, and accompanied by a very long

A "cold snap."

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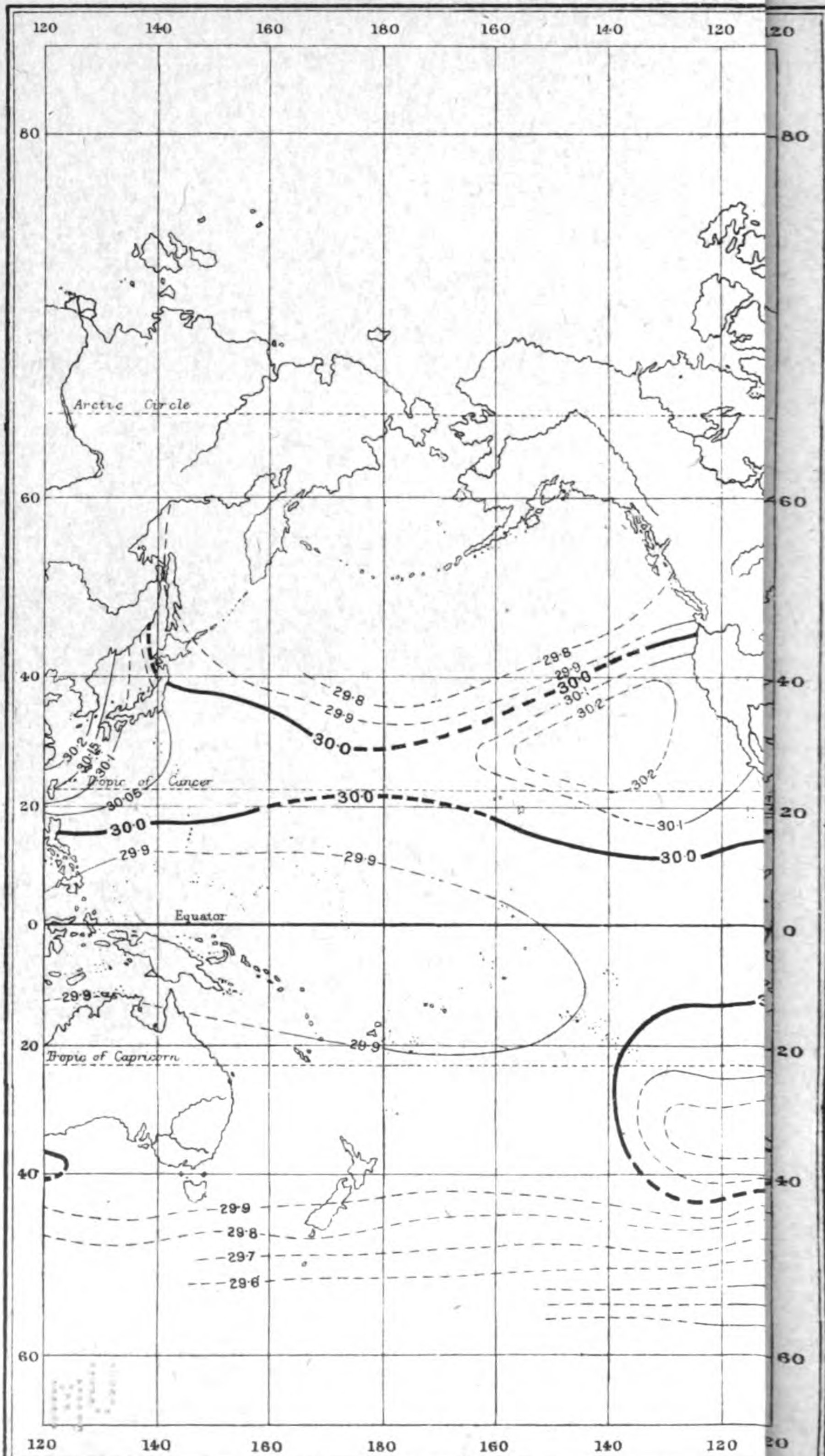

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area of bitterly cold northerly winds. It was this latter doubly unwelcome visitor which rendered the storm so specially disastrous to human as well as animal life. The centre of the disturbance passed almost completely over New York, and, pushing its way to the northward and eastward, skirted closely the shores of the United States. It is an instance where the law of storms, founded on a hard-and-fast circular theory and 8-point bearing, would be almost wholly inapplicable; and there is now no doubt that there are many such to puzzle the unhappy navigator who may be caught in their meshes.

Permanent areas of high and low pressure.

Here it seems opportune to refer to a phase of the subject deserving of the most careful study. In various parts of the world there are certain *permanent* areas of high and low pressure, which exercise a stupendous influence on the general atmospheric circulation. These will be found depicted on the accompanying chartlets, which seamen will find useful. In addition to the more permanent pressures, there are certain other areas which vary with the season of the year. The most marked of these extend over Central Asia, and appear to cause the N.E. and S.W. monsoons of India.

Their importance.

As might be expected, the "Synchronous Charts" shew precisely the same feature. Take, for example, the anti-cyclone found on the edge of the Tropics, extending at times across the ocean from Africa to America, at other times contracted to smaller dimensions on the eastern half of the sea, and occasionally stretching northward to the British Isles and Iceland. Other systems, both of high and low barometer, are found travelling about in all directions and disappearing; but this particular anti-cyclone is permanent, being only modified in its shape and extent; and if some means could be devised for ascertaining the changes in its northern limits from day to day, one of the greatest difficulties of the weather forecaster in this country would be overcome, very few of the disturbances reaching the shores of Great Britain and Ireland which are not influenced by it.

Influence of land.

This brings us to the question as to whether the intervention of high land has any influence in altering the track of a storm. Until comparatively recently, West India hurricanes were believed to travel along the northern shores of the islands, and curve round to the north and north-east with the trend of the American coast, because it was thought the land formed a barrier against their advance into the interior of the continent. This theory, once very generally accepted, is demolished by the fact that many disturbances originating in the Tropics take other directions: some pass into the Gulf of Mexico, and thence north-eastward across the States to the Atlantic again; while others proceed due north, or even eastward of north, from their place of origin in mid-ocean.

Effect of land.

The invariable rule is for areas of low barometer to cling to the neighbouring anti-cyclone; and it is to this, and not to the contiguity of land, that the direction of storm translation is related.

Exactly the same action is observable over the northern part of the Atlantic. Cyclones do not alter their course because they reach the shores of Europe, but because of the conditions of pressure over Europe itself. Land certainly modifies the *intensity* of a cyclone, but seems to have no direct influence upon the course it may take. This explains the multiplicity of directions in which cyclones travel over sea and land. The neighbourhood of Newfoundland, in about lat. 40° N., is more frequented than any other portion of the Atlantic, disturban es being attracted here from the south, the west, and the north-west; but, continuing their journeys, some pass into the Arctic regions through Davis Strait, while others take any direction between that and the Gut of Gibraltar, always liable to a change of direction when approaching any anti-cyclonic area which may happen to lie either directly across their paths or alongside them.

Velocity of travel.

Then, again, the apparent rate of travel of a storm is affected by the distribution of barometic pressure in the vicinity; and the track assumed for it is as erratic over the open sea as over a mountainous region. Some synchronous charts afford most perplexing storm tracks. The meteors seem to go full speed ahead at from 30 to 50 miles an hour, as against the usual average of 15, for some time; then they stop, or go dead slow; and again put on full speed. Not distribution of pressure, but mistaken inference, is the more usual cause of this alleged err tic action. Assuming that some storms cross the North Atlantic in one quarter of the time occupied by precisely similar meteors, then it is obvious that, without a knowledge of the meteorological conditions over the ocean in between, any attempt to predict United Kingdom weather on the departure of a storm from the United States must very often prove a dismal failure.

Synchronous Weather Charts shew a remarkable difference be-

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tween the energy of cyclonic systems over land, as compared with those over sea. Rarely does the wind in the disturbances crossing America rise to a gale, but immediately the moist atmosphere over the Gulf Stream is reached, the depth of the cyclone rapidly increases, and heavy gales are frequent.

Energy over land and sea.

Passing from the Atlantic into Europe, the converse is manifest; the barometer rises, and the gales die out; in fact, it is certain that the stay-at-home inhabitants of these isles have no conception of the force of a regular Atlantic "howler." On shore, even during the worst gales, the surface force of the wind is broken up by the numerous obstacles met with, but on the wide ocean there is nothing to check the full fury of the blast.

Wind force on the ocean.

It will thus be seen that synchronous charts let in a flood of light on what was very obscure before. Nor have observers in other parts of the world been idle. Their investigations prove that those terrible convulsions of nature, which, according to location, are variously denominated Hurricanes, Cyclones, or Typhoons, are all closely allied to each other, and to gales in general.

In research of this kind, the seafaring community is much indebted to the voluntary labours of the late Hon. Ralph Abercromby, F.R. Met. Soc., who devoted the major portion of his life to this particular study. As an extensive traveller, Mr. Abercromby had facilities denied to professional men, who, except during a holiday, always too brief to permit of wide explorations, are tied to their offices, whatever these may be. To get in touch with such men abroad, and in the hope of personally encountering at least one cyclone, Mr. Abercromby visited, in 1885-1886, the observatories at Mauritius (the very stronghold of tempests), Madras, Calcutta, Manila, Hong-Kong, and Tokio. By this means he was able not only to procure more recorded material for his investigations, but to learn, in course of conversation, certain minute but important details which could not be extracted from existing reports. On his return to this country, Mr. Abercromby embodied the results of his experience in various papers read before the Royal and other Societies, and by his kind permission the writer has availed himself of occasional extracts, of which the following, "On the relation between Tropical and Extra-tropical Cyclones," are deserving of careful consideration.

A pains-taking traveller.

Conclusions.

All cyclones have a tendency to assume an oval form; the longer diameter may lie in any direction, but has a decided tendency to range itself nearly in a line with the direction of propagation.

The centre of the cyclone is almost invariably pressed towards one or other end of the longer diameter ; but the displacement may vary during the course of the same depression.

Tropical hurricanes are usually of much smaller dimensions than extra-tropical cyclones ; but the central depression is much steeper and more pronounced in the former than in the latter.

Tropical cyclones have less tendency to split into two, or to develop secondaries than those in higher latitudes.

A typhoon, which has come from the tropics, can combine with a cyclone that has been formed outside the tropics, and form a single new, and perhaps more intense, depression.

No cyclone is an isolated phenomenon ; it is always related to the general distribution of pressure in the latitudes where it is generated. The concentric circles, hitherto drawn to represent a cyclone, ignore the fact that a cyclone is always connected with and controlled by some adjacent area of high pressure.

In all latitudes pressure often rises over a district just before the advent of a cyclone. The nature of this rise is at present obscure; but the character of the unusually fine weather under the high pressure is identical both within and without the tropics.

In all latitudes a cyclone which has been generated at sea appears to have a reluctance to traverse a land area, and usually breaks up when it crosses a coast line.

After the passage of a cyclone in any part of the world there is a remarkable tendency for another to follow very soon, almost along the same track.

The velocity of propagation of tropical cyclones is always small, and the average greatly less than that of European depressions.

There is much less difference in the temperature and humidity before and after a tropical cyclone than in higher latitudes. The quality of the heat in front is always distressing in every part of the world.

The wind rotates counter-clockwise in every cyclone of the northern hemisphere ; and everywhere as an in-going spiral. The amount of incurvature for the same quadrant may vary during the course of the same cyclone ; but in most tropical hurricanes the incurvature is least in front, and greatest in rear, whereas in England the greatest incurvature is usually found in the right front. Some observers think that, broadly speaking, the incurvature of the wind increases as we recede from the equator.

The velocity of the wind always increases as we approach the central calm in a tropical cyclone ; whereas in higher latitudes the strongest winds and steepest gradients are often some way from the centre. The portion of a cyclone which is of hurricane violence forms, as it were, a kernel in the centre of a ring of ordinarily bad weather. In this peculiarity tropical cyclones approximate more to the type of a whirlwind tornado ; but the author does not think that a cyclone is only a highly developed whirlwind, as there are no transitional forms of rotating air.

The general circulation of a cyclone, as shown by the motion of the clouds, appears to be the same everywhere.

All over the world unusual coloration of the sky at sunrise and sunset is observed not only before the barometer has begun to fall at any place, but before the existence of any depression can be traced in the neighbourhood.

Cirrus appears all round the cloud area of a tropical cyclone, instead of only round the front semi-circle as in higher latitudes. The alignments of the stripes of cirrus appear to lie more radially from the centre in the tropics, instead of tangentially to the isobars, as indicated by the researches of Ley and Hildebrandsson in England and Sweden respectively.

The general character of the cloud all round the centre is more uniform in than out of the tropics; but still the clouds in rear are always a little harder than those in front.

Everywhere the rain of a cyclone extends farther in front than in rear. Cyclone rain has a specific character, quite different from that of showers or thunderstorms; and this character is more pronounced in tropical than in extra-tropical cyclones.

Thunder and lightning are rarely observed in the heart of any cyclone, and their absence is a very bad sign of the weather. Thunderstorms are, however, abundantly developed on the outskirts of tropical hurricanes.

Squalls are one of the most characteristic features of a tropical cyclone, where they surround the centre on all sides; whereas in Great Britain squalls are almost exclusively formed along that portion of the line of the trough which is south of the centre, and in the right rear of the depression. As, however, we find that the front of a British cyclone tends to form squalls when the intensity is very great, the inference seems justifiable that this feature of tropical hurricanes is simply due to their exceptional intensity.

A patch of blue sky in the centre of a cyclone, commonly known as the "bull's-eye," is almost universal in the tropics, and apparently unknown in higher latitudes. This blue patch does not apparently always coincide exactly with the barometric centre. The author's researches show that in middle latitudes the formation of a bull's-eye does not take place when the motion of translation is rapid; but as this blue space is not observed in British cyclones when they are moving slowly, it would appear that a certain intensity of rotation is necessary to develop this phenomenon.

The trough phenomena—such as a squall, a sudden shift of wind and change of cloud character and temperature just as the barometer turns to rise, even far from the centre—which are such prominent features in British cyclones, have not been even noticed by many meteorologists in the tropics. The author, however, shows that there are slight indications of these phenomena everywhere; and he has collated their existence and intensity with the velocity of propagation of the whole mass of the cyclone.

Every cyclone has a double symmetry. One set of phenomena, such as the oval shape, the general rotation of the wind, the cloud ring, rain area, and central blue space, are more or less related to a central point. Another set, such as temperature, humidity, the general character of the clouds, certain shifts of wind, and a particular line of squalls, are more or less related to the front and rear of the line of the trough of a cyclone.

The author's researches show that the first set are strongly marked in the tropics, where the circulating energy of the air is great and the velocity of propagation small; while the second set are most prominent in extra-tropical cyclones, where the rotational energy is moderate and the translational velocity great.

The first set of characteristics may conveniently be classed together as the rotational; the second set as the translational phenomena of a cyclone.

Tropical and extra-tropical cyclones are identical in general character, but differ in certain details due to latitude, surrounding pressure, and to the relative intensity of rotation or translation."

In the above the word "trough" frequently occurs, and it becomes necessary to explain what Abercromby means by it. He says, "The 'trough' of a cyclone is a line drawn through the centre, more or less at right angles to the direction of translation, through all points where the barometer, after having reached its lowest, has just turned to rise."

Axis and line of progression.

The word "axis" is sometimes improperly used to denote the storm path. The axis of a storm's parabolic track is the straight line drawn through focus and vertex, and the vertical axis is an imaginary line, "more or less vertical," round which the whirl revolves.

The reader will not fail to notice the words "more or less vertical"; they are rendered necessary by the contention of some writers that storms do not move parallel to the surface of the earth, but are tilted up, so that one side may pass over without being felt nearly so much as the other.

Difficulty in foretelling weather.

The highest authorities concur in admitting that, even with the advantage of many combined simultaneous observations at stations some distance apart, such as can be obtained on land by a special and regularly organized service, it is impossible at present to foretell *with certainty*, for even one day in advance, the precise character of the coming weather.

If, then, concerted action avails so little, what chance has an isolated individual, such as the commander of a ship, who has nothing to guide him but his own local observations, of satisfying himself as to the weather he may expect for even a single coming day?

Barometrical paradoxes.

Where is the sailor who has not been urged to prepare for dirty weather by the warning of an unusually low glass, to find that the disturbance has passed away wide of his position? Let him not, however, regret his trouble, but console himself with the wise "saw" that "it is better to be sure than sorry," and with the knowledge that, though his guide has now deceived him, on the next occasion its monition may be more than justified.

On the other hand, he should bear in mind the fact that stiff gales sometimes blow with quite a high barometer. This is common enough in the English Channel with the wind at N.E., but it also happens with strong blows from other quarters. For example, though the writer, on the last day of January, 1880, while on a passage from Philadelphia to Liverpool, experienced a fresh gale from the *Southward*, with a heavy sea, yet, during the worst of it, the glass never fell below 30″·20, and the sun shone brilliantly, with scarcely a cloud in the heavens. On the previous day, with moderate wind at S.E. by E., it ranged as high as 30″·50.

Instance of abnormally high pressure.

Many people will doubtless remember the anti-cyclone which, in January of 1882, persistently hung over the British Islands for several days, and excited wonder by the high reading of the barometer, which reached 30″·80. The writer was then returning home from the United States, and the following, taken from the log, shews that the region of unusual pressure extended a long way to the westward.

"Noon, Tuesday, January 17th. Lat. 47° 40′ N., and Long. 26° 53′ W. Wind S. ½ W. (true), moderate breeze; light clouds; sun dimly visible at intervals. Barom. 30″·42, Thermom. in open air (shade) 54°.

"Noon, Wednesday, January 18th. Lat. 49° 19′ N., and Long. 19° 52′ W. Wind S. by W. (true), light to moderate breeze. Sun shining brightly. Hazy on horizon. Barom. 30″·70, Thermom. 53°.

"At 9 P.M. Barom. attained its highest reading, viz.:—30″·80.

"Noon, Thursday, January 19th. Lat. 50° 46′ N., and Long. 12° 17′ W. Wind S.E. by S. ½ S. (true), light. Sun shewing occasionally through breaks. Horizon very clear and well defined. Barom. 30″·75, Thermom. 47° in open air (shade)."

The point of both examples lies in the *high* glass and *southerly* wind, which latter, in the first one quoted, actually reached the force of a fresh gale.

Barometric gradient. All this would appear an enigma did we not know, as will presently be explained, that gales depend not so much upon the absolute *height of the glass* as upon the *difference between two readings* at places some little distance apart.

If, over a given area, the glass be *uniformly high*, or *uniformly low*, there will be but little wind; but when the barometric incline between places of relatively high and low pressure is abrupt, the winds will be violent.

Disabilities of seamen. To the sailor, however, who is not behind the scenes, and cannot be in telegraphic communication with other places for comparison of barometers, and has, moreover, his own observations vitiated to a considerable degree by his vessel's onward progress, this knowledge is practically worthless.

What he desires is to be enabled to augur, from the study of his own instruments and the aspect of sea and sky, what is likely to take place around him, and, unfortunately, it is but seldom that this is possible to any noteworthy extent.

If we could only know what was going on in the higher regions of the atmosphere simultaneously with existing surface conditions, out of apparent chaos might come some sort of order; this, however, is a difficulty which at present is insuperable.

Unfailing signs. There are, however, certain indications which, when they occur, may be regarded as pretty reliable, and are in consequence worthy of being logged in red ink.

For example, a rising barometer with a southerly wind presages fair weather, whilst a falling barometer with a northerly wind conveys a warning which cannot be disregarded with impunity. To make this applicable to either hemisphere, it would be as well, perhaps, to substitute the words Equatorial for Southerly, and Polar for Northerly.

Influence of tack on Barometer. Another rule of equal importance has reference to the effect of a ship's tack on the barometer. The *cause* will be evident, as explained hereafter; for the present it is sufficient to state the *fact*.

In the Northern hemisphere, with all winds, except when near the equator, the starboard tack takes a ship towards a higher barometer, whilst the port tack takes her towards a lower one.

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In the Northern hemisphere, with all winds, except when near the equator, the starboard tack takes a ship towards a higher barometer, whilst the port tack takes her towards a lower one.

It follows, *that in every case a rising barometer on the port tack is a valuable indication of improving weather, while on a starboard tack, a falling barometer is a great warning.* This order is reversed in the Southern hemisphere.

Barometer over-rated as an instrument of *Prediction.*

The cases just quoted, with one or two minor ones which will appear by-and-by, are the exceptions which prove the rule, that—opposed though it may seem to older teaching—the barometer, under most circumstances, *when taken singly and unsupported by other indications,* can no longer be regarded as an infallible weather oracle.

Its warnings are uncertain, and, on some occasions, its movements are only contemporaneous with the commencement of the disturbance they are supposed to herald, as friction in the tube and inertia must first be overcome before the altered pressure of the air can put the mercury in motion.

Nevertheless there are special instances, and most of us will remember them, when—other indications being wanting—its silent fall has revealed an impending danger. We must, therefore, by no means cast off our old friend, or too hastily underrate its value.

Daily Barometrical tides.

In making delicate observations, it should be known that the mercury is subject (quite apart from the weather) to regular daily tidal influences. At between 9 and 10 A.M. and P.M. it is, so to speak, high water. Then commences the ebb, which lasts until between 3 and 4 A.M. and P.M. respectively. The mean range in tropical regions is about the tenth of an inch, but as the latitude increases, the tidal range diminishes, until finally it almost vanishes at the poles.

In our own part of the world this phenomenon is often unnoticed, owing to its lesser degree, and its being frequently masked by accompanying and stronger atmospheric changes. Not so nearer the equator, where the greater tidal range, the more equable character of the weather, and the ordinary barometric fluctuations being both infrequent and small in amount, render it easily apparent.

The practical lesson to be learned from this noteworthy peculiarity is, that to some extent changes in the barometer are of increased or diminished significance, in accordance as they disagree or agree, with the regular tidal rise and fall. Thus, if the mercury drop steadily between the hours of 3 and 9, when according to the above law it should be rising, the indication is of more importance than if occuring between 9 and 3, the period of tidal ebb.

So far this singular phenomenon of barometric tides has puzzled physicists, and though many hypotheses have been advanced, none of them seem capable of affording an entirely satisfactory solution.

Barometer movements in low latitudes.

It must be remembered that though, as before observed, considerable barometric changes are infrequent near the equator, when they *do* occur they are of proportionately greater significance. In low latitudes, a sudden fall of any magnitude is invariably followed by a hard blow, which, however, is mostly of a transitory character; bearing out the familiar adage, "Long foretold, long last; short notice, soon past."

The seaman is, perforce, a weather forecaster, independent of extraneous assistance when out of sight of land; although it must not be forgotten that, even he, when in control of wireless apparatus, is now more nearly approximating to the shore weather telegraphist. When a storm is in the vicinity, the restlessness of the mercurial column of the barometer, or even a sudden rise under certain conditions, is an indication that trouble is brewing. Very early in the history of the laws of storms seamen came to the conclusion that a very rapid fall in the barometer of a ship under the influence of a cyclonic storm, pointed out a system of small diameter but great intensity; whereas a gradual fall portended a more extensive storm of lesser force; and the lowest barometer reading of all was to be found at the centre of the cyclone. It was also noticed that the bearing of this lowest pressure was related to the direction in which the wind was blowing at any given place on the surface of the globe. Facing the point of the compass whence blows the storm wind, in the Northern Hemisphere, it was found that the lowest pressure of the barometer, coincident with the centre of the disturbance, was about eight points on the right hand. For the Southern Hemisphere we have merely to substitute "left hand" for "right hand" in the above.

Action of the mercury in a barometer.

This principal is generally known as Buys Ballot's Law, after the Dutch meteorologist who first aroused attention to its universal applicability; and may be expressed as follows. Facing the wind the lowest barometric pressure is on the right hand of the observer in the Northern Hemisphere and on his left hand in the Southern Hemisphere. Very often, with corresponding changes, the rule is expressed as though the observer were back to the wind. In other words, the wind of a cyclonic storm blows along the isobars with less pressure on the right hand in the Northern Hemisphere and on the left hand in the Southern Hemisphere; observer facing the wind in either case. This law, even for light winds, is approximately true. Buys Ballot's Law does not hold good close to the equator; but cyclonic storms are practically unknown there.

So-called Buys-Ballot's Law.

Wind is air in motion, and when in rapid motion it becomes a storm. There are various theories as to the cause of storms or cyclones. Heinrich Dove, a native of Silesia, Professor of Natural Philosophy at Berlin, and subsequently Director of the Royal Meteorological Institute, held the view that cyclones are formed when two great air currents—polar and equatorial—flow side by side, storms being the eddies formed along the line of junction. It is to be kept in mind that the qualities of the atmosphere in the front portion of a cyclone are quite different from those in the rear—the former being warm, moist, and depressing; while the latter are cold, dry, and exhilarating. This is one of the chief objections made to the circular theory by its opponents, who contend, logically enough, *that if one and the same air current were moving in a circle, it would be difficult to explain the rapid thermal changes which certainly take place with the veering of the wind as the storm passes over.*

Storms—how caused.

Abercromby, however, points out that these thermal changes do not occur to nearly the same extent in tropical cyclones, and though the essential character of all cyclones is very much the same, authorities are agreed that there are important points of difference, and this is one. Undoubtedly those of the tropics are more symmetrical in shape than their half-brothers of the temperate zones; they are also more violent, their movement of translation is slower, and their diameter is less. The facts here mentioned confirm the writer in the opinion expressed in the first edition of "Wrinkles," that there are varieties of cyclones, depending chiefly upon local peculiarities: indeed, Abercromby practically says as much: and whilst all are governed by some general law or laws, there are controlling circumstances which impart to each kind its distinctive features.

Various classes of cyclones.

All this would point to great complexity not easily unravelled by the sailor, so completely cut off as he is from all outside help. In the case of actual cyclones, whether they be of a spiral, oval, or circular kind, some of the old rules laid down for the guidance of seamen will, in the absence of better ones, still apply. It is just as well, therefore, to remember them.

How to manœuvre in Cyclones

HEAVE-TO on the starboard tack in the Right-hand semi-circle, and port-tack in the Left-hand semi-circle, in *both* hemispheres.

CARRY-ON on starboard tack in Northern, and port tack in Southern hemisphere.

SCUD when on line of progression in either hemisphere; or in Left-hand semi-circle in Northern, or Right-hand semi-circle in Southern hemisphere.

It will of course be understood that, looking towards the direction in which the body of the storm is moving, the Right and Left-hand semi-circles lie respectively on the right and left-hand of the line of progression.

In his intercourse with brother seamen, the writer has often heard it contended that the rule saying that if the wind veers to the right, the observer is in the Right-hand semi-circle, and *vice versâ*, is *not* to be depended on, as in their experience they had sometimes found the very opposite to be the case, which, of course, shook their faith on other points as well. The rule, however, is perfectly sound, *but it is only intended to be used by a vessel that is stationary.*

Rule to determine semicircle.

If the reader will imagine his ship to be *overrunning a slow moving* circular storm, *which is travelling on the same course as* *himself,* he cannot fail to see, with the aid of Piddington's Horn Card, or a tracing-paper substitute for it, that when passing through either semi-circle, the wind will veer the contrary way to the rule, as it is usually interpreted. Possibility of being misled.

On first falling in with a supposed cyclone, a fair surmise may be made as to the direction in which it is moving, since it is known that these disturbances favour a particular course in each locality, which course is now pretty well mapped out for the various parts of the world. Nevertheless, under all circumstances (and bearing in mind the liability to mistake referred to above, and the possibility of unexpected re-curvature), it will be prudent to heave-to or stop the engines until the ship's position with respect to its path is well ascertained. In either hemisphere, when a sailing ship is about to heave-to in order to determine the approximate bearing of the storm centre and the semi-circle in which she happens to be, it is well to adopt that tack which would be proper for the dangerous semi-circle. To ascertain path of storm—heave-to.

Remember, *whatever may be said to the contrary,* that from the varying area of storms, and the difference of barometric gradients which must therefore exist between their centres and outer edges, *it is quite impossible to estimate the distance of the vortex by the height of the mercury, or by its rate of fall.* Distance of centre, impossible to estimate.

This statement is accentuated by the fact that an area of depression is not necessarily circular in shape, if indeed it ever does more than roughly approximate to a circle, and that the gradients are by no means uniform. In some parts the lines of equal pressure (Isobars) run together much closer than at others, and no rule can be formulated to meet such eccentricities.

Further, the more precise analyses made in late years of the paths of cyclones seem to prove that the motion of the centre itself is sometimes erratic in more ways than one. Not only is its velocity along the path variable, but the centre sometimes sways about, or wobbles, to such an extent as to describe a little loop. In this connection a word of caution is necessary. None but observations of the greatest exactitude, and taken at an absolutely defined geographical position, are of the least use for these intricate inquiries. Such data are still wanting! Eddying movement of centre.

This much, however, is certain—if the barometer rise while the wind diminishes, the meteor is passing away; but if it continue to fall, and the wind and sea to increase, the meteor is approaching, or the depression is deepening and spreading. "He who watches his barometer, watches his ship" is therefore more than usually applicable.

Having ascertained, beyond doubt, which semi-circle you are in, *wait no longer,* but carry on sail on the starboard tack if in the Northern hemisphere, or port tack if in the Southern hemisphere; and when unable to do so through loss of spars or canvas, heave-to on the starboard tack if in the Right-hand semi-circle, or the port tack if in the Left-hand semi-circle. By Tack on which ship will bow the sea.

so doing, instead of being continually headed off as the wind veers, you will come up and bow the sea.

Again, while first hove-to waiting for things to develop themselves, should the barometer fall rapidly, and the indications of an approaching hurricane become stronger, whilst the wind continues to blow steadily, but with increasing violence, *from the same point*, or nearly so, you will know that your vessel is directly in the path of the advancing storm. Then to escape being involved in the centre and most dangerous part, up helm and scud before the wind, *keeping it, at all hazards, a couple of points or three on the starboard quarter in the Northern hemisphere, or on the port quarter in the Southern hemisphere.* There is, however, an exception to this.

Rule for scudding.

Reference has already been made to the highly important discovery of Meldrum, that, in cyclones of the Southern Indian Ocean, "the north-easterly and easterly winds often, if not always, blow towards the centre." It therefore becomes necessary to make special provision for vessels caught in these cyclones, but, owing to the elements of uncertainty which always exist regarding their true position in the storm field, this is no easy matter. Abercromby, even in the light of Dr. Meldrum's great experience, is not quite certain which is the safest way to treat them. In the Southern hemisphere the Left-hand semi-circle is the dangerous one, and, with the wind from the southward and eastward, should you run to the N.W. in front of the storm's path, the centre may overtake you before getting clear on the other side. On the other hand, if you remain hove-to, the storm may curve to the southward and go for you straight. This, coupled with the inblowing propensity of the winds in rear of the storm, makes the situation a delicate one.

Exception to rule for scudding

On the southern side of the true storm field there is a belt of *intensified S.E. trade wind*, in which the barometer falls fast, and the wind increases in force *without changing its direction*, though the ship may be far away from the line of progression of the vortex. If she were on the line of progression, she would equally experience an increasing and unchanging wind with a falling barometer; but the trouble is, that there is no *certain* means of knowing whether the ship is on the line of progression, or only in the belt of intensified Trade. Under these circumstances the ordinary rules say "Run," but Meldrum's advice is to lie-to till the barometer has fallen $\frac{6}{10}$ths of an inch. When the mercury has fallen this much below the normal (say to 29″·30), and the weather still gets worse, run to the N.W.; but Abercromby makes this conditional on the behaviour of the clouds. In effect, he puts it thus:—*Should their direction remain persistently more to the South than the surface S.E. trade, then run at once to the N.W. even if the barometer has not fallen $\frac{6}{10}$ths of an inch. If, however, the wind remain in the S.E., with the squalls increasing in violence, and the clouds*

Belt of intensified S.E. Trade.

Uncertainty as to ship's position.

driving either in the same direction as the surface wind, or a little more to the eastward, no attempt should be made to run to the N.W. till the barometer has fallen as before stated. It is then about equally hazardous to remain hove-to or to run. (Pleasant!!)

The horns of a dilemma.

Abercromby—basing his recommendations on Meldrum's rules—goes on to say that "A steamer anywhere in this belt of intensified trade wind, with a falling barometer, should try and force her way to the S.E. or E."

"Ships bound to the S.W., and encountering strong N., N.E., or E. gales, with a falling barometer, should lie-to till the mercury turns upwards, and the appearance of the weather improves. Hurricanes in the Southern Indian Ocean move so slowly that this may involve lying-to for four or five days."

"With wind between N. and E. when a cyclone is travelling to the S. or S.E.—that is, when the hurricane is recurving—make as much easting as possible, either under sail or steam."

Cloud observation gaining ground.

Of late years the value of *cloud observation* has been gradually recognised among scientists; at one time—not so very distant—such observations were deemed only suitable for rustics or for ignorant sailors, the tendency *on shore* being to rely too much on instruments, and too little on the appearance of the sky. Happily this state of things has passed away, and clouds are formally included in the *science* of meteorology. Some are of opinion that any further progress that may be possible in the method of handling ships in hurricanes will come from cloud observation. When the characteristic cirrus-veil first forms over the sky, the direction in which the cloud is densest is most probably the direction of the vortex. Later on, as the cyclone approaches, a heavy bank of hurricane cloud appears on the horizon, and where this is densest, there will the centre be.

Clouds indicating bearing of centre.

The centre will bear more nearly 8 points from the direction of the motion of the lower clouds, than from that of the surface wind. For instance, in the Northern hemisphere, if the surface wind were West, the low clouds might come from W.N.W., and the bearing of the centre would be N.N.E.

We now come to the time-honoured rules of the late Admiral Fitzroy, which, so far as they go, are intrinsically good. They will well repay the trouble of committing them to memory, but it must not be overlooked that many of them have only *local* significance.

"Whether clear or cloudy—a rosy sky at sunset presages fine weather; a sickly, greenish hue, wind and rain: tawny or coppery clouds, wind: a dark (or *Indian*) red, rain: a red sky in the morning, bad weather, or much wind (perhaps also rain): a grey sky in the morning, fine weather: a high dawn, wind: a low dawn, fair weather.

A 'high dawn' is when the first indications of daylight are seen above a bank of clouds. A 'low dawn' is when the day breaks on or near the horizon, the first streaks of light being very low down.

"Soft-looking or delicate clouds foretell fine weather, with moderate or light breezes: hard edged oily-looking clouds,—wind. A dark, gloomy blue sky is windy; but a light, bright blue sky indicates fine weather. Generally, the *softer* clouds look, the less wind (but perhaps more rain) may be expected:

Form of clouds and colour of sky.

and the harder, more 'greasy,' rolled, tufted, or ragged,—the stronger the coming wind will prove. Also—a bright yellow sky at sunset presages wind: a pale yellow, wet: orange or copper coloured, wind and rain—and thus by the prevalence of red, yellow, green, grey, or other tints, the coming weather may be foretold very nearly—indeed, if aided by instruments, almost exactly.

"Light, delicate, quiet tints or colours, with soft, indefinite forms of clouds, indicate and accompany fine weather: but gaudy or unusual hues, with hard, definitely outlined clouds, foretell rain, and probably strong wind.

"Small inky-looking clouds foretell rain:—light scud clouds, driving across heavy masses, show wind and rain; but if alone, may indicate wind only—proportionate to their motion.

"High *upper* clouds crossing the sun, moon, or stars, in a direction different from that of the lower clouds, or the wind then felt below, foretell a change of wind toward *their* direction. Between the tropics, or in the regions of the Trade Winds, there is generally an upper and counter current of air, with very light clouds, which is not an indication of any approaching change. In middle latitudes such upper Currents are not so frequent (*or evident?*) except before a change of weather.

"After fine clear weather, the first signs, in a sky, of a coming change are usually light streaks, curls, wisps, or mottled patches of white distant cloud, which increase and are followed by an overcasting of murky vapour that grows into cloudiness. This appearance, more or less oily, or watery, as wind or rain will prevail, is an infallible sign.

"Usually the higher and more distant such clouds seem to be,—the more gradual, but general, the coming change of weather will prove.

"Misty clouds forming, or hanging on heights, show wind and rain coming—if they remain, increase or descend. If they rise or disperse, the weather will improve, or become fine.

Formation of dew.

"Dew is an indication of coming fine weather. Its formation never *begins* under an overcast sky, or when there is much wind.

"Remarkable clearness of atmosphere, especially near the horizon; distant objects, such as hills, unusually visible, or well defined; or raised (by refraction); and what is called 'a good *hearing* day,' may be mentioned among signs of wet, if not wind, to be expected in a short time. Much refraction is a sign of easterly wind.

"More than usual twinkling or apparent size of the stars; indistinctness or apparent multiplication of the moon's horns; haloes; 'wind-dogs,' and the rainbow; are more or less significant of increasing wind, if not approaching rain, with or without wind."

Echoes, phosphorescence, and lightning.

By English fishermen an echo at sea is considered a sign of coming easterly wind, and it is generally thought that much phosphorescence of the water, or a vivid display of the Aurora, is the prelude to a southerly gale in our own latitudes; whilst lightning in the N.W. never fails, in the North Atlantic, to be followed by a heavy gale from same quarter.

From time immemorial the weather-wise have had their weather-signs, and among them in great profusion are to be found the habits of birds, beasts, and fishes. Most people know what to expect when swallows fly high or low, donkeys bray, or sea birds are found far inland. Spiders, gnats, ants, and more particularly leeches, exhibit indications of weather fluctuations; so do bees, which cannot without peril be peeped at over a hedge forty yards off when weather of the kind they dislike is imminent; it is a case of the *coming* bee and the *going* man.

Pigs are supposed to see wind, and even certain plants are sensitive to atmospheric changes: so with a host of other things —organic and inorganic. There is the tradition of a shepherd on Salisbury Plain, who, on a bright sunshiny day, confidently warned the passing traveller of the coming shower, because, as it turned out on enquiry, he had noticed the ram of his flock scratching himself in a gorse-bush. There is no doubt about it, animals know a great deal more about the proximate weather changes than man does; and our finest and most delicate meteorological instruments are as yet, on this point, far inferior to their natural sensibility. Though this be so, it fails to benefit the sailor who cannot turn his ship into a Noah's Ark, except on those rare occasions when Mr. Barnum and his "biggest show on earth" brave the ocean in pursuit of the "Almighty dollar."

Behaviour of animals.

This chapter would manifestly be incomplete without some reference to the Moon as a factor in meteorological matters. It is pretty generally believed by sailors and farmers, that it exercises some sort of mysterious influence at the Full, Change, and Quarters, and is in fact prime agent in everything that concerns the weather. Patient and laborious research, extending back over half a century, has completely failed to establish such connection. "As an attracting body causing an ærial tide, it has of course an effect, but one utterly insignificant as a meteorological cause.†

Popular delusion concerning Moon's influence on weather.

The lunar hypothesis of weather changes is founded on a plausible but false analogy between ocean and atmospheric movements, the fallacy of which consists in the fact, that while *the tides* are undoubtedly caused by the attraction of the moon, coupled with the earth's diurnal rotation, modified by obstructing continents and other large tracts of land, *air-currents* are produced primarily by the changes of temperature, and consequent differences of density, of large masses of air depending on the combined action of the successive incidence of the sun's rays on different areas of the earth's surface, the constant high tempera-

Imperfect reasoning.

† Sir John F. W. Herschel, Bart. *Good Words*, 1864.

ture of the equatorial zone, the alternating extremes of heat and cold in the arctic regions, and the different radiating power and humidity of land and water.*

Equinoctial disturbances

So also with 'Equinoctial Gales.' They constitute one of those prejudices of which it is well nigh hopeless to disabuse the popular mind. Most careful observations prove conclusively that storms have no special connection with the Equinoxes; yet how often does one hear a gale, occurring even three weeks one side or other of this event, referred to as an 'Equinoctial Gale.'

Many even intelligent sailors are imbued with the notion that the moon, when near the full, has a tendency to clear the sky of clouds, or, as they phrase it in the language of the fo'k'stle, to "skoff" them up. Close observers have turned their attention to this point also, and so far it is a drawn battle—opinion being about equally divided.

We are all involuntarily much more strongly impressed by the fulfilment than by the failure of our expectations: so it is that the sailor seizes upon an occasional coincidence of this sort, and points triumphantly to it as a proof of the correctness of his theory, whilst he omits to record the many instances in which the weather provokingly failed to behave in the manner he anticipated.

To all but hypercritical folk of the type of Herschel or Arago, the evidence that connects the Moon with weather changes is irresistible: old Jobson the carrier finds no difficulty about it at all, nor do any of his cronies. Their ancient system may be flouted by the learned, but *they* have faith in it, for has it not been handed down from generation to generation? It is quite plain, as the company at "The Jolly Traveller" have remarked over and over again, that when the crescent moon is on her back it is going to be dry, but that when the hollow part is downwards, it will rain. "Plain as turning up this here pot," says old Jobson, who has just finished his pint, and lets the few last drops fall to the ground.

The oracle speaks.

The stars, too, speak with no uncertain voice to this class of weather prophet; if they are clear it is a sign of rain; if they are "misty" it will be wet; if they are clouded, the rain is pretty sure to come before long. And, curiously enough, down comes the rain, often in less than a week. Who has not met the man with a particular corn which is barometer and thermometer in one, or a faithful knee-joint which has twinges whenever the forces of the air gather themselves for storms?

* See Appendix I.

Some rustic weather prophets are very amusing: ask one whether it will be a fine day to-morrow, and he will look in his mug, slowly shake his liquor round, take his pipe from his mouth, and say oracularly, "Weather isn't what it used to be." By pressure you get a promise of a fine day, "if the wind don't drop," accompanied by another saving clause that "he don't half like them yaller clouds." He, and two or three other old fellows, who have been shepherds, or have been to sea, bear the burden of the public weather upon their shoulders, for they are consulted by almost everyone they meet as to "what they think of it to-day," and, having reputations to uphold, must be oftentimes much disconcerted by the unstable conduct of the elements. But your weather prophet generally, like the oracle-worker of old, understands the protective possibilities of language, and avails himself of them. **Rustic weather prophets**

When one considers that the Moon quarters weekly, it would indeed be curious if a change of some kind or another did not occur within a day or so (either way) of that event. And as, in this variable climate, "spells" of weather seldom last more than four or five days, it does not require a very lively imagination to connect them with the constantly recurring phases of the moon. He must therefore be an ill-informed, obstinate, or very credulous fellow who, in the face of the positive dictum of science, continues to pin his faith to the played-out fallacies and charlatanism of the old style almanacs, which, relying upon the gullibility and ignorance of the public, oft-times contain the most unmitigated rubbish. A curious endeavour, by a Fellow of the Royal Astronomical Society, to prove "that the moon not only influences the weather, but is the actual cause of it," received a shock in 1893 from which it will never recover. If any believer in weather cycles depending upon the moon will take the trouble to compare this gentleman's published predictions with the winds and weather actually experienced in the first half of the year, he will get a sickener of self-appointed prophets. **Old style almanacks.** **Supposed cycle of 62 years.**

It is natural that Britishers should be deeply interested in any discovery—scientific or non-scientific—which promises to be an infallible guide in predicting the weather. Situated in the direct path of disturbances from the Atlantic, these Isles are subject to extreme and sudden climatic variations; dry and wet, hot and cold days follow each other so quickly as to give no definite ture of the equatorial zone, the alternating extremes of heat and cold in the arctic regions, and the different radiating power and humidity of land and water.*

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Old style almanacks.

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SHERIDAN'S RHYMING CALENDAR.

January—Snowy.	July—Moppy.
February—Flowy.	August—Croppy.
March—Blowy.	September—Poppy.
April—Showery.	October—Breezy.
May--Flowery.	November—Wheezy.
June—Bowery.	December—Freezy.

Another Irishman describes the weather in his native "counthry" as follows:—

Dirty days hath September,
April, June, and November.
From January up to May,
The rain it raineth every day.
All the rest have thirty-one
Without a blessed gleam of sun;
And if any of them had two and thirty,
They'd be just as wet and twice as dirty!

The cautionary legend respecting West Indian Hurricanes runs thus:—

June—too soon.
July—stand by.
August—look out you must.
September—remember.
October—all over.

In this chapter, Ocean Meteorology has been only lightly touched upon. It is impossible to do more. Carefully study the information on matters marine meteorological contained in No. 6 of the list of necessary books; become regular co-operators with the British Meteorological Office, the United States Hydrographic Office, or a similar institution, by recording specified observations in the logbooks, or on the forms, which are supplied for the purpose by those State-supported Offices, so as to keep in close touch with current weather; and forward the data to the respective head quarters, at short intervals. Meanwhile see the haulyards coiled down clear for running; and, above all, keep your *weather* eye open, for the shipmaster is perforce a weather forecaster and not a weather telegraphist.

For wind pressure and velocity see page 710.

CHAPTER XVII.

TIDES, CURRENTS, WAVES, AND BREAKERS.

To enter into a disquisition on the complete theory of the tides would in these pages be both unprofitable and impracticable; for, apart from its extent and intricate character, as well as the intimate knowledge required of higher mathematics, there are perhaps few physical subjects which are still at the present time on the whole more unsatisfactory.

Tide theory not altogether satisfactory.

Seeing how very complicated and relatively varying are the circumstances out of which the tides are evolved, to say nothing of differences still existing on certain points, a precise and consolidated elucidation of the subject hardly seems possible. Before the end of this chapter is reached the reader will probably be of the same opinion.

We must look to the future to produce some commanding genius who, by special devotion to the subject, will be able to reconcile discrepancies, harmonise procedure, and be accepted by common consent as *the* authority of the day.

Any seaman, therefore, who is desirous of making a *special* study of the tidal theory, must refer to the various works by distinguished men in which this comprehensive subject is treated at great length. The article containing the latest and most complete information is that by the late Sir G. H. Darwin, in the *Encyclopædia Britannica.* The late Mr. Richard A. Proctor, in his magnificent work *Old and New Astronomy,* dealt with certain phases of the subject from an original point of view; and Lord Kelvin, dating back to 1869, has done his share, by inaugurating the method of *Harmonic Analysis* in connection with continuous tidal records obtained from the automatic gauges now coming into general use at the principal ports of the world. In the methods of observation, and in the methods of reduction, the entire theory of the tides owes much to Lord Kelvin, who has now completed the practical part of the subject by inventing and constructing the famous tide-predicting engine. So expeditious is this machine, that the tides of a port for a whole year can be fully worked out in a couple of hours.

Harmonic analysis.

But it is here proposed, after giving a brief sketch of the general laws and features, to draw the seaman's attention to value to the orthodox meteorological prophecies, which only venture on the probabilities of a day, and even then are frequently far from being absolutely reliable. For England, about the best almanac going is

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October—all over.

In this chapter, Ocean Meteorology has been only lightly touched upon. It is impossible to do more. Carefully study the information on matters marine meteorological contained in No. 6 of the list of necessary books; become regular co-operators with the British Meteorological Office, the United States Hydrographic Office, or a similar institution, by recording specified observations in the logbooks, or on the forms, which are supplied for the purpose by those State-supported Offices, so as to keep in close touch with current weather; and forward the data to the respective head quarters, at short intervals. Meanwhile see the haulyards coiled down clear for running; and, above all, keep your *weather* eye open, for the shipmaster is perforce a weather forecaster and not a weather telegraphist.

For wind pressure and velocity see page 710.

CHAPTER XVII.

TIDES, CURRENTS, WAVES, AND BREAKERS.

To enter into a disquisition on the complete theory of the tides. would in these pages be both unprofitable and impracticable; for, apart from its extent and intricate character, as well as the intimate knowledge required of higher mathematics, there are perhaps few physical subjects which are still at the present time on the whole more unsatisfactory.

Tide theory not altogether satisfactory.

Seeing how very complicated and relatively varying are the circumstances out of which the tides are evolved, to say nothing of differences still existing on certain points, a precise and consolidated elucidation of the subject hardly seems possible. Before the end of this chapter is reached the reader will probably be of the same opinion.

We must look to the future to produce some commanding genius who, by special devotion to the subject, will be able to reconcile discrepancies, harmonise procedure, and be accepted by common consent as *the* authority of the day.

Any seaman, therefore, who is desirous of making a *special* study of the tidal theory, must refer to the various works by distinguished men in which this comprehensive subject is treated at great length. The article containing the latest and most complete information is that by the late Sir G. H. Darwin, in the *Encyclopædia Britannica.* The late Mr. Richard A. Proctor, in his magnificent work *Old and New Astronomy*, dealt with certain phases of the subject from an original point of view; and Lord Kelvin, dating back to 1869, has done his share, by inaugurating the method of *Harmonic Analysis* in connection with continuous tidal records obtained from the automatic gauges now coming into general use at the principal ports of the world. In the methods of observation, and in the methods of reduction, the entire theory of the tides owes much to Lord Kelvin, who has now completed the practical part of the subject by inventing and constructing the famous tide-predicting engine. So expeditious is this machine, that the tides of a port for a whole year can be fully worked out in a couple of hours.

Harmonic analysis.

But it is here proposed, after giving a brief sketch of the general laws and features, to draw the seaman's attention to certain points which will have a *practical* interest for him, inasmuch as, upon an understanding of *some* of them at least, the safe navigation of his ship will depend.

To a right appreciation of the subject one must begin at the beginning, and, therefore, a few words about the properties of water, and the nature and origin of waves, are indispensable to lead off with.

There are four descriptions of sea waves, namely, "Wind waves," "Storm waves," "Earthquake waves," and "Tidal waves."

Properties of water. Though it has been proved that water is capable of being compressed, it is the case to such a very limited extent, that for our present purpose the property may be disregarded. A forced displacement, therefore, at one point of a liquid surface, is always exactly counterbalanced by a corresponding rise at another. Conversely, a rise at any place can only be effected by a proportionate withdrawal of water elsewhere. This being understood, it is not difficult to see that the first-named kind of wave is produced by **Wind Waves.** a purely *mechanical* action. The wind does not blow exactly parallel to the surface, but strikes downward, and causes a depression at the point of impact, which is instantly answered by an equal elevation elsewhere. This elevation or wave—slight at first—must necessarily have the same height *above* the general sea-level or plane of repose that the depression or trough had *below* it.

As the wind increases in strength and duration, these undulations of the water grow larger, and eventually form immense billows, which have been recorded as sixty feet in height from trough to crest.

Formation of wind waves. Sir W. H. White, in his *Manual of Naval Architecture*, says:— "If the wind is at first supposed to act on a smooth sea, and then to continue to blow with steady force and in one direction, it will create waves which finally will attain certain definite dimensions. The phases of change from the smooth sea to the fully formed waves cannot be distinctly traced. It is, however, probable that changes of level, elevations and depressions, resulting from the impact of the wind on the smooth surface of the sea, and the frictional resistance of the wind on the water, are the chief causes of the growth of waves.

"An elevation and its corresponding depression once formed, offer direct resistance to the action of the wind, and its unbalanced pressure producing motion in the heaped-up water, would ultimately lead to the creation of larger and larger waves. This is probably the chief cause of wave growth, frictional resistance playing a very subordinate part as compared with it. So long as the speed of the wind relatively to that of the wave water is capable of accelerating its motion, so long may we expect the speed of the wave to increase; and with the speed the length, and also the height.

"Finally the waves reach such a speed that the wind force produces no further acceleration, and only just maintains the form unchanged; then we have the fully grown waves. If the wind were now suddenly withdrawn, the waves would gradually decrease in magnitude, and finally die out. This degradation results from the resistance due to the molecular forces in the wave—viscosity of the water, &c.—and when the waves are fully grown, the wind must at every instant balance the molecular forces.

"If the water were a *perfect* fluid (the particles moving freely past one another), and if there were no resistance to motion on the part of the air, the waves once formed would travel onwards without degradation."

Height of waves depends on "Fetch."

The height of wind-waves depends on what is called the "Fetch;" that is, the distance from the weather shore or place where their formation commences. According to the late Mr. Thomas Stevenson (author of *Lighthouse Illumination*), the following formula is nearly correct during heavy gales, when the fetch is not less than about six nautical miles:—height of wave in feet is equal to 1·5 × by the square root of the fetch in nautical miles. As an example, let us suppose that during a violent gale the wave formation commenced at a distance of 625 miles from the observer:—The square root of 625 is 25, which, multiplied by 1·5, gives 37½ feet as the height of the waves at the end of their long journey.

Occasional groups of large waves during gales

Every sailor has noticed the occasional grouping together of three or four huge waves larger than the general run. These are probably caused by the exceptional force of the *squalls* which occur at intervals in nearly every gale of wind. From the inequality in their respective speeds, it follows that any particular set of large waves will not reach the vessel side by side with the wind which produced them. Such a thing would be very unlikely—one might almost say impossible; so that these big fellows, deriving their energy only in part from the blast sweeping over them at any given instant, come rolling along, as often as not, during a lull in the violence of the gale.

"Storm waves" are due to an entirely different cause. On

Storm waves.

the outer or *anticyclone* edge of hurricanes the barometer stands abnormally high, indicative of great atmospheric pressure; whilst at the centre or vortex the mercury falls unusually low, and, accordingly, *there* the pressure is least. Between the centre and outer edge a difference of 3·5 inches in the height of the mercury has been recorded; equal to a difference of pressure of 248 pounds on the square foot of surface at these two places. It will readily be seen that the effect of this encircling belt of high pressure, and internal area of low pressure, coupled with the incurving of the wind, is to produce a heaping up of the water under the body of the cyclone, whose highest point is necessarily at the centre, where it is, so to speak, sucked up in a measure.

As the hurricane travels bodily onward, this "storm wave"—which, according to the shape of the disturbance, may be likened to an oval dish or a soup plate, bottom up—accompanies it; and has been known more than once to inundate low-lying districts, and cause thousands of human beings to perish at one sweep. In the delta of the Húgli, 100,000 lives have been lost by a single visitation of this kind.*

Earthquake waves.

"Earthquake," or "Great Sea Waves," as they are technically styled, differ entirely in their origin from the two preceding. They are frequently spoken of as "*Tidal Waves;*" but as the tides have nothing whatever to do with them, such a designation is obviously wrong.

The term "Great Sea Wave" is used in contradistinction to "Great Earth Wave," which latter is the name given to the disturbance experienced on land.

An earthquake may have its centre of impulse either inland or under the bed of the ocean. In the first case, when the "Great Earth Wave," or superficial undulation, coming from inland, reaches the shores of the sea (unless these be precipitous, with deep water) it may lift the water up, and carry it out on its back, as it were; for the rate of transit of the shock is sometimes so great that the heap of water lifted up has not time to flow away towards the sides.

At Arica, in Peru, and other places, this sudden going out of the sea has laid bare the bottom of the bay, and left ships aground which only a few minutes before were riding quietly at anchor in several fathoms of water.

As soon as the shock is over, the body of water thus forced out to sea returns as a huge wave, and, on approaching a sloping shore, rears up like a wall, and breaks with overwhelming force.

* Appendix K.

Sometimes, however, its volume, height, and velocity are so great that it comes ashore *bodily*, and breaks far inland, causing even greater destruction to life and property. At Arica, the *Wateree* —a "Double-ender" belonging to the United States Navy—was carried inland quite a distance by the reflux, and remained in evidence for many years. If the writer's memory is not at fault, she was carried clean over the railway embankment.

When the seat of disturbance is beneath the ocean, the "Great Sea Wave" rushes in upon the land as before—with this difference, that it is not preceded by the water retiring from the foreshore, as in the first case.

Curious effect of earthquake waves.

These submarine shocks are sometimes so severe, that the sensation has been conveyed to those afloat as if the ship were violently bumping over a sunken reef. In one instance which came under the writer's observation, the inkstand on the captain's table of one of the Pacific Company's coast steamers was jerked upwards against the ceiling, where it left an unmistakable record of the occurrence; and yet this vessel at the time was steaming along in smooth water, many hundreds of fathoms deep. The concussions were so smart that passengers were shaken off their seats, and, of course, thought that the vessel had run ashore. When the non-elastic nature of water is considered, there will be no difficulty in understanding how such an effect could be produced.

About the most notable instance of a "Great Sea Wave" occurred during the stupendous and ever-memorable eruption in August, 1883, which had for its centre the Island of Krakatoa, in the Strait of Sunda. On this occasion the loss of life amounted to 37,000, caused chiefly by the sea waves, one of which attained the almost incredible height of 135 feet. Its effects were traced on all the principal Tide-gauges of the world, and were even observed at Havre, some 11,000 miles from their source of origin.

A full account of this eruption, which was investigated in detail by committees and sub-committees of the Royal Society, comprising many of the leading scientists of the day, has been published in a volume of nearly 500 quarto pages, under the editorship of the late Mr. G. T. Symons, F.R.S. In this book every branch of the phenomenon and its effects have been most thoroughly dealt with, and is consequently well worth perusal.

Lastly, we come to the purely *vertical* oscillations of water. known as "Tide Waves."

The distinctive difference between these and "Wind Waves" lies in the fact that the last-mentioned are only *surface* disturbances, which, however violent the gale, reach at no time to a greater depth than 50 fathoms, and are virtually only local and temporary in their action. Whereas "Tide Waves" are the result of an *outside attraction, which continuously affects the whole mass of water on the earth's surface.*

Tide caused by joint attraction of sun and moon.

The Tides are popularly attributed to the Moon *only*, but in point of fact they are caused by the *joint* attraction of both Sun and Moon overcoming, to a small extent, the power of terrestrial gravity, whereby the water is held to the earth. It is due to this double influence, which sometimes pulls in the same and at other times in a contrary direction, that we have the ever-varying phases in the times and heights of High and Low Water.

Duration of a tide.

The general motion of the Tides consists in an alternate *vertical* Rise and Fall, and *horizontal* Flow and Ebb, occupying an average period of half a Lunar day, or about 12 hours 25 minutes. This vertical movement is transmitted from place to place in the seas, like an ever-recurring series of very long and swift waves.

In theory, "Tide Waves" occur simultaneously at points of the earth's surface diametrically opposite to each other, and are termed Superior or Inferior, according as they are formed on the side next the Moon, or on the one opposite. It will be understood, therefore, that theoretically there are *two* tide waves at a fixed distance apart of 180°, measured both in latitude and longitude, and that they are constantly travelling round the earth from East to West.

Since, as already explained, water may be regarded as practically devoid of elasticity, and cannot be raised at any point without being proportionally lowered at some other, it follows that, midway between each of these waves of High Water, there are depressions of the surface corresponding to what we term Low Water. This is shewn in *Diagrams Nos.* 1 *and* 2, where, however, for convenience as much as from necessity, the matter of *scale* is entirely disregarded.

S is the Superior High Water, *I* the Inferior. *L* and *L'* represent Low Water. As may be supposed, the Inferior Tide Wave is a shade smaller than the other.

"Full and change."

At the period of "Change" or New Moon, when it and the Sun are in Conjunction, that is to say, when they are on the same side of the earth, as shewn in *Diagram No.* 1,—and at the period of Full Moon, when they are said to be in Opposition

Diagram No. 1.

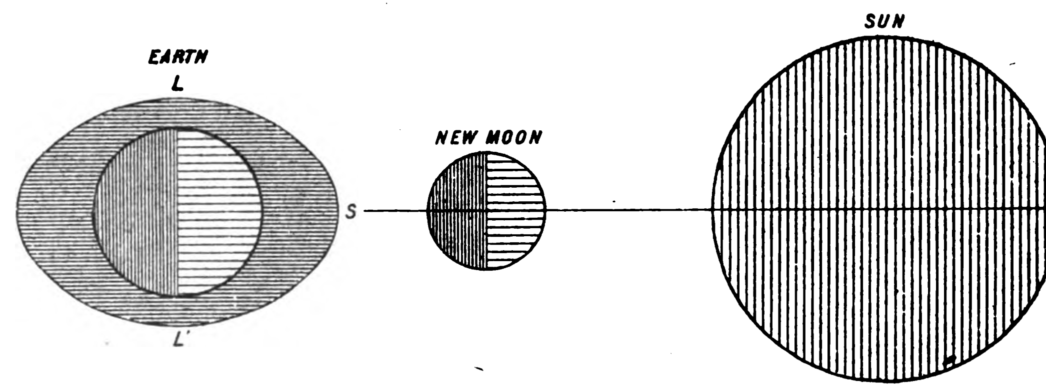
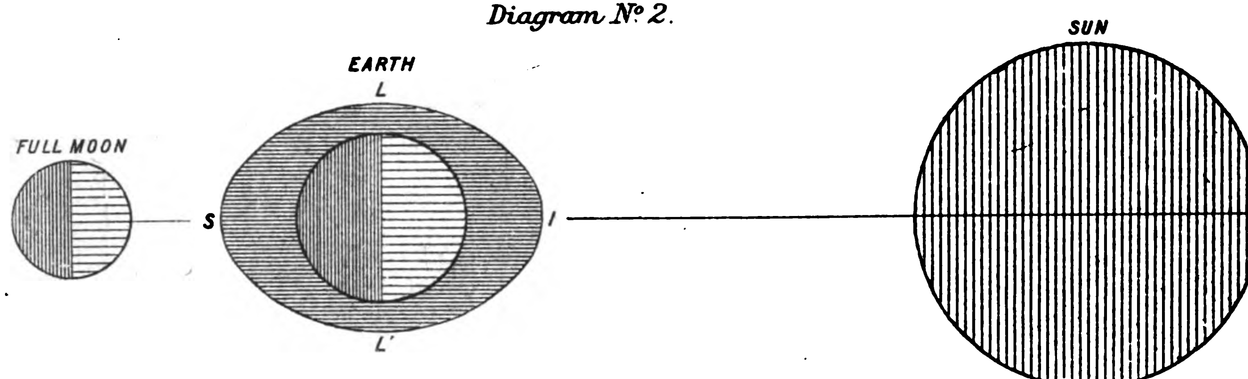


Diagram No. 2.



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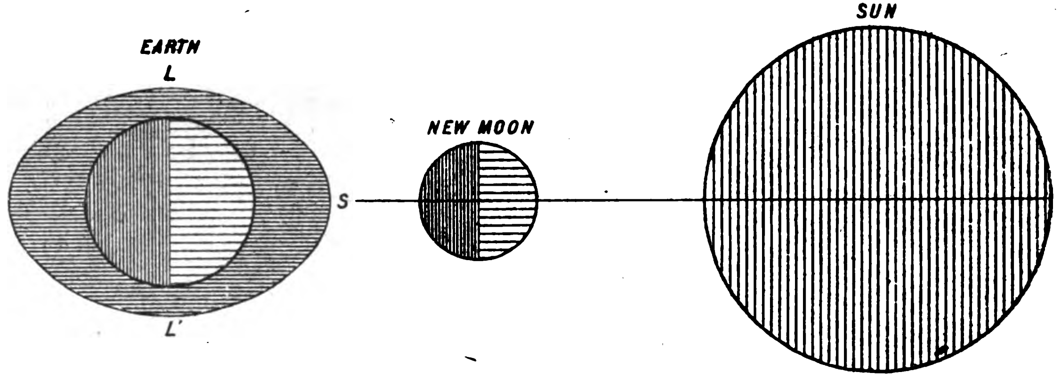
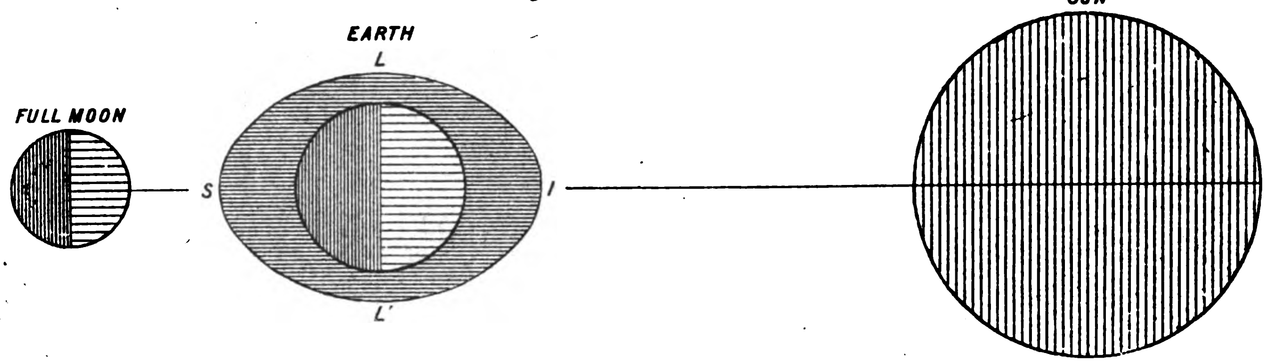


Diagram No. 2.



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that is, with the earth between them, as shewn in *Diagram No.* 2,—the greatest tidal effect is produced, as at such times the solar and lunar influences act in unison, and are exerted in the same straight line.* This is the period of "Springs;" and

* Our satellite, the moon, is a dark globular body, 2,162 miles in diameter, which shines solely by reflected light received from the sun; consequently, at the period termed "new moon," when the sun and moon pass the meridian together at mid-day, the moon is invisible to us, as at such times she occupies a position in the heavens almost directly between the earth and the sun, and accordingly presents to us her unenlightened face; which is still further hidden by the dazzling brightness of that particular part of the sky (*vide Diagram No.* 1). Moon's diameter.

But when the moon is at the "full," she passes the meridian at midnight, or 12 hours after the sun, which latter, being then on the opposite side of the earth, illumines the whole of that hemisphere of the moon which is next to us (*vide Diagram No.* 2).

It is obvious that, in the intermediate stages, a greater or less amount of the moon's illumined face must be visible to us.

A day or so after new moon, when her bright portion is crescent-shaped, it is not unusual in clear weather to see the remainder or obscure part also. At such times the brightly illuminated cusps or horns seem to extend *beyond* the darker portion of the disc, and hold it in their grasp. This condition is commonly alluded to as "the old moon with the young in its arms," or "the moon on its back." The phenomenon of the bright part of the moon appearing to encircle the remainder, is due to an optical illusion termed "Irradiation," in virtue of which, white objects, or those of a very brilliant colour, when seen on a dark ground, look larger than they really are. The new moon appearing after this fashion, is asserted by some to be the *sure* forerunner of bad weather. A statement so positive in character should have something to support it, but, unfortunately for those who make it, it is not at all justified by the known facts. For example, in many favoured parts of the world, the condition of the atmosphere is mostly *always* propitious to seeing the young moon in the arms of the old; and accordingly, in such localities it possesses no particular signification. On the other hand, in countries given to a chronic state of mist and haze, the phenomenon, from its rareness, attracts more attention, and indicates an *unusual* clearness in the air, which, according as it is backed up by other signs, may or may not herald the approach of rain or wind. From the roving nature of his calling, the sailor, more than other men, should be on his guard against the *general* application of what are only intended as *local* weather signs. That which denotes one kind of weather in one place may signify something totally different in another; much in the same way that in the northern hemisphere the barometer rises for northerly winds, but falls for the same wind in the southern hemisphere. These remarks apply also to *some* of the late Admiral Fitzroy's weather signs, given on pages 257-258. Now, as the moon is only supposed to be rendered visible to us by the light reflected from the side presented to the sun, it may not unreasonably be asked why it is that, as just observed, we sometimes see the obscure as well as the brighter portion. This is easily understood, however, by recollecting that when the moon is one or two days old, the relative positions of the earth, the moon, and the sun, are such as permit the earth to reflect the sunlight back to the moon in sufficient quantity to faintly illumine that hemisphere which is next to ourselves. In fact, we give it *Earth-light.* Irradiation. Earth light.

It is obvious that, to an inhabitant of the moon (if such there could be), our earth must appear as a splendid moon, shining with light borrowed from the sun, and presenting all the moon's own phases as seen from the earth, but possessing more than three times her apparent diameter. We act, therefore, in the same capacity towards the moon that the moon does towards us. It is interesting here to note the opinion of some scientists, that, judging from the moon's physical conditions, life, as *we* know it, cannot exist there; whilst it is possible, if not probable, that some of the other planets (more especially Mars, which has been termed "the miniature of our earth") may have their inhabitants, though not necessarily beings of precisely the same order as ourselves.

Spring tides.

should it occur when both luminaries happen to be at their nearest approach to the earth, say in January, the effect is enhanced. In this way, the high tides which occur about the latter end of March and September are known as "Equinoctial Springs." Owing to a specially favourable combination of astronomical positions, some spring tides are exceptionally great, in which case they are termed "Extraordinary Springs."

Datum line of soundings on Admiralty Charts.

With the exception of Liverpool, Milford, and Holyhead, and perhaps two or three other ports, the soundings on Admiralty charts and plans are all reduced to *mean low water of Ordinary Springs*. The *lowest known tide* is the French datum.

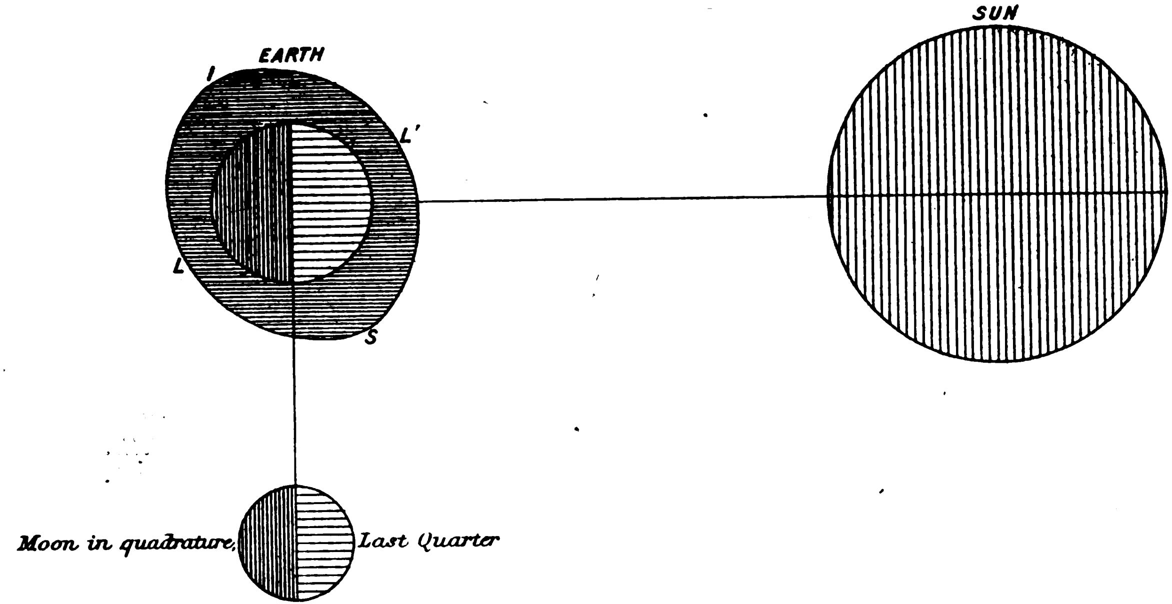
It is to be regretted, however, that for want of a permanent mark cut into rock or masonry, the value of this zero is not always obtainable. Moreover, owing to the great variability of low water ordinary springs, this Admiralty-adopted datum does not appear susceptible of an exact scientific definition. It would be better to reckon the various High and Low Waters as so much above or below the Mean Sea Level of the place referred to. Similarly, the chart soundings might be referred to the same plane, which, putting "meteorological" tides on one side, is practically constant.

When the moon is in quadrature, or 90° distant from the sun —that is to say, when one passes the meridian six hours ahead of the other—their actions neutralize each other to a large extent, by the tendency to produce *four* independent waves; two under the sun, of course on opposite sides of the earth, and two similarly situated under the moon. In this case the action of the sun lowers the waters of the sea at the same point where the moon would raise them, and conversely. Each pulls in a different direction to the other—a regular "Tug of War,"—and thus the tides at such times are less in every way, and get the name of "Neaps." It stands to reason, however, that the change from springs to neaps, and *vice versa*, is gradual. As the moon in her course travels from the position of either "new" or "full," the solar and lunar waves in each hemisphere separate until the moon arrives in quadrature; they then commence to close again, and so on *ad infinitum*.

Neap tides.

It must not be understood, however, even in theory, that two separate or distinct tide waves are then really traversing the ocean in each hemisphere. Such is not the case. The single effect observed is compounded of both influences, and is virtually the same as if, after the moon had given a form to the waters,

Diagram No. 3.



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the sun had modified it, both as to size and position; so that the place at which the resultant high water really occurs is at a point intermediate to them both, but nearer to the lunar wave, since it is the greater of the two.

Springs are thus *the sum*, and neaps *the difference* of the co-existing lunar and solar tides. And since the sum of the lunar and solar tide-generating forces is nearly three times their difference, the *range* of spring tide will usually be nearly three times that of neap tide. Diagram No. 3 represents neap tides as produced at the last quarter of the moon, and as the effect at the first quarter is precisely similar, it is not worth while to give the diagram.

The tidal wave is also accelerated or retarded in a way which will now be described. To put it in other words, the interval between the moon's passage over the meridian and H.W. varies sensibly with the moon's age. In the 1st and 3rd quarters of the Moon the solar tide is *westward* of the lunar one; and, consequently, the actual High Water (which is the result of the combination of the two waves), will be to the *westward* of the place it would have been at if the Moon had acted alone, and the time of High Water will therefore be hastened. In the 2nd and 4th quarters the general effect of the Sun is, for a similar reason, to produce a retardation in the time of High Water. This effect, brought about by the relative positions of the Sun and Moon, is called the *Priming* and *Lagging* of the tides. It deranges the average retardation, which, from a mean value of nearly 51m., may be augmented to 66m. at neaps, or be reduced to 38m. at springs.*

Priming

Lagging.

Herein, then, is a most intricate and ever-changing combination of influences, more especially when viewed in connection with those still to be mentioned. The waters of the ocean are therefore subject to a ceaseless conflict between the disturbing and ever-varying forces exercised by the Sun and Moon respectively, but in a manner which is recurrent and is being ever repeated in enhanced or diminished degree. To include every change in the relative positions of the two luminaries, requires a period of over 18 years, and where accurate tidal observations have been continuously made for that length of time, it is not only possible, but easy, to predict the times and heights for any future period.

A study of the preceding diagrams will shew that the greatest and least water is to be found on a bar at High and Low Water respectively of Spring Tides; whilst at Neaps the tide will neither rise so high nor fall so much. There is therefore more water on a bar at Low Water Neaps than at Low Water Springs. Further-

Half-tide, or mean sea level

* See Appendix J.

more, we have the important fact that *at half tide the depth on a bar is always nearly the same, whether it be Springs or Neaps.* Half-tide corresponds to the Mean sea level, which is constant over a limited area, and should therefore be universally adopted as the standard Plane of reference within that area.

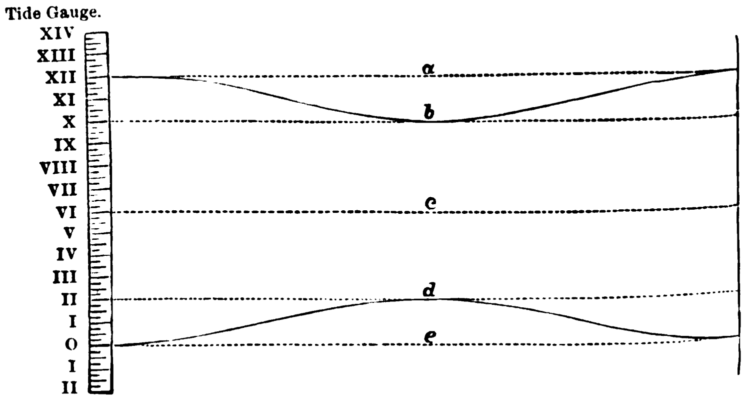
Half-tide mark referred to datum of National survey.

Every port should have its half-tide level accurately determined and recorded in its archives. It should be permanently marked in a conspicuous position of easy access. Where the Admiralty Tide Tables give the half mean spring range, the corresponding figures on the Tide-gauge should be set to the half-tide mark. The gauge would thus be in agreement with the tabular heights, and its zero would represent whatever had been accepted as mean L.W.O.S. In taking soundings, their reduction would then be a very simple affair, which is far from being the case at the present time. It would almost appear as if surveyors, having determined L.W.O.S., had in many instances purposely set the zero of the gauge considerably lower *to be on the right side.* This is just about as idiotic as keeping one's clock always five minutes fast of the real time.

Zero of tide gauge.

The following diagram, taken from the Admiralty Tide Tables, is intended to explain the terms Spring Rise, Neap Rise, and Neap Range, as made use of on the Charts and in the Sailing Directions published by the Admiralty. In foreign countries a different notation is used, markedly in France and the U.S.A.

Tidal diagram.



a = Mean Level of High Water, Ordinary Springs.
b = " " " Neaps.
c = Half Tide or Mean Level of the Sea both at Springs and Neaps.
d = Mean Level of Low Water Ordinary Neaps.
e = " " " Springs.

EXAMPLE.

Spring Rise (or Mean Spring Range)	= e to a	=	12 ft.
Neap Rise - - -	= e to b	=	10 „
Neap Range - - -	= d to b	=	8 „

Be careful to distinguish between Neap Rise and Neap Range.

The term "range" is used to express the amount any given tide rises above and falls below the mean sea level, and these two quantities are supposed to be equal; but owing to the varying effects of wind, atmospheric pressure, diurnal inequality, and local causes, this is not always the case. To find accurately the half tide, or M.S.L., it is necessary to eliminate the "meteorological" tides, and the only way to do this is to extend the observations over a long period of time so as to get rid of irregularities by averages. This would give the most perfect tide-table: the height and time could subsequently be modified in accordance with the meteorological phenomena experienced on any given day. There is yet another point in connection with "range." It has been stated already that at the Equinoxes the *spring* range is greatest, that is to say, the water rises to a higher and falls to a lower level. But on the other hand the *neap* range is least. The trial of strength between sun and moon is then being fought out on more equal terms, and, as a consequence, where the opponents are so evenly balanced, their bone of contention is less disturbed.

Meteorological tides.

In summer, when the sun is most distant from the earth, it is the other way about; the neap range is then greater and the spring range is less, with the result that the difference between the various high and low waters in a semi-lunation is not so marked, or, in other words, the general sea-level is less disturbed.

Now, with reference to a tide wave being formed simultaneously on *both* sides of the earth. In considering this question we will temporarily put the sun on one side, as by so doing matters will be much simplified, without in the least interfering with the general principle.

Superior and inferior tide waves.

At first sight it looks strange that the Inferior wave should be produced by the *attraction* of a single body, such as the moon, which of course cannot be on *both* sides of the earth at the same instant of time. Admitting the attractive power of the moon, it is easy to comprehend that the Superior tide may be so formed; but that the other should *also* be the result of a pull in the same direction, is much more difficult to understand, and proves an effectual poser to many who, from want of the key, consider the matter as contrary to common sense. Touching the latter, it must be allowed that common sense is a first-rate thing in its way, and happy are those who possess it, but unfortunately, it is not always equal to unravelling intricate problems, of whatsoever kind: if it were, then it follows that the nation need not pay so much for Board Schools, nor in fact foster education in any form. The moon's *attraction* undoubtedly causes *both* tide waves, and, absurd as the idea may appear to many, the fact is capable of sufficiently easy explanation, which we will now attempt.

Universal attraction or gravitation.

It is necessary, first of all, to have a clear conception of that species of attraction called Gravitation, which pervades all space —*every particle of matter in this vast universe attracting every other particle.*

It is therefore a force of interaction, but apart from this and the fact that—unlike the radiant forces of Light, Heat, and Sound —*its effect is instantaneous at all distances*, we know absolutely nothing as to its nature. So far it remains seemingly an impenetrable mystery.

The laws governing Universal Attraction are well established, and may be thus stated :—

"1. All bodies in nature exert a mutual attraction upon each other, at all distances, in virtue of which they are continually tending towards each other.

"2. For the same distance the attractions between bodies are proportional to their masses.

"3. The masses being equal, the attraction varies with the distance, being inversely proportional to the square of the distances asunder." *

Explanation of how the tides are formed by attraction.

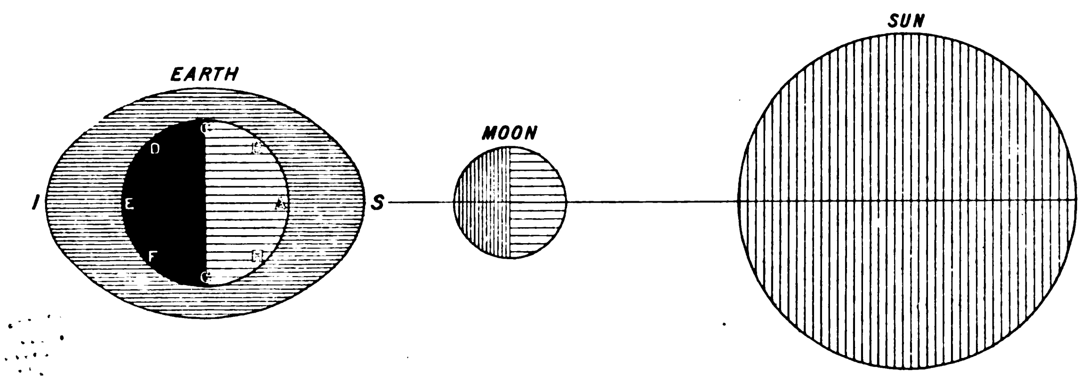
The tides, however, are not due to the simple attraction of the moon upon the waters of the globe, but to the *difference* of her attraction on the near and far sides of the earth.

Now, the moon attracts the solid earth as well as the waters upon it, and in conformity with law No. 3, she attracts most that which is nearest to her. Therefore, the waters on the side next the moon are most drawn to her, the solid earth in a lesser degree, and the waters on the distant side less still; so that the latter are left behind, as it were, and present the illusory appearance of being *attracted towards 1*, which, however, is not the case. See *Diagram No.* 4.

Let the inside letters represent points on the earth's surface, and let us suppose the latter to be uniformly covered with water. Now, the different parts of the earth are at unequal distances from the moon. Hence the attraction which the moon exerts at *a* is greater than that which she exerts at *b* and *h*, and still greater than that which she exerts at *c* and *g*; while the attraction at *e* is least of all.

* *Ganot's Popular Natural Philosophy.* A most engaging book, which no officer should be without

Diagram No. 4.



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The attraction of the moon upon the layer of water immediately under her at the point *S* is greater than that which she exerts upon the solid globe; the water will therefore heap itself up over *a*—that is, High Water will take place immediately under the moon. The water which thus collects at *a* is derived from the regions *c* and *g*, where the quantity of water must therefore be diminished—that is, there will be Low Water at *c* and *g*.

The water at *I* is less attracted than the solid mass of the earth. The latter will therefore recede from the waters at *I*, leaving them behind, so that they will be heaped up also, and produce High Water at the same time as at *S*. The Moon's attraction, as exercised upon our earth, is *differential* in its character, and herein lies the gist of the whole thing.

So much for the Moon; now for the Sun.

Sun's influence on the tides.

The sun produces tidal effects similar to those of the moon. He is the centre and controlling force of the system to which we belong; and his attractive power upon the earth, *as a whole*, is vastly greater than that of our comparatively puny satellite; for, though the sun's mean distance from us is 388 times that of the moon, it is more than counterbalanced by his mass, which is 26½ million times greater than that of the moon. Nevertheless, the latter's influence upon the tides is nearly 2⅛ times more than the sun.

Sun's mean distance.

Here we have another seeming anomaly, but it is explained by the fact that the sun's mean distance is so great (nearly 93 millions of miles), that the *inequality* of his attraction on *different* parts of our earth is very small; that is to say, the sun attracts *all* parts of our comparatively small globe in a *nearly* equal ratio, which is not by any means the case with the moon, as the earth's equatorial diameter (7,926½ miles) bears a considerable proportion to her mean distance from us of 238,830 miles. The moon is only removed from us by a distance equal to 30 of the earth's diameters, whereas it would require about 11,700 earths to bridge the space between the sun and ourselves. In other words, the sun's attraction, as applied to our earth, is less *differential* in character than that of the moon.

Moon's mean distance.

The term Gravitation is applied more especially to the attraction exerted between the heavenly bodies. The sun being that member of our planetary system which has the largest mass, exerts also the greatest attraction, from which it might seem that the earth and the other planets ought to fall into the sun, by reason of this attraction. This would indeed be the case, if they were

Planetary orbits.

only acted upon by the force of Gravitation; but owing to their inertia,* the original or primary impulse which they once received constantly tends to carry them away from the sun in a straight line. The *resultant* of this acquired velocity, and of the force of Gravitation, makes the planets describe curves about the sun which are elliptical in shape, and are called their orbits.

Similarly, it can be shewn that, were it not for terrestrial gravitation acting in opposition to solar and lunar gravitation, the waters of the earth would be attracted altogether away from it. The sun, our own planet, and its satellite, are therefore constantly at war, struggling for the supremacy in this respect, and the yielding waters obey first one and then the other according to the force preponderating at the moment.

Velocity of tidal wave.

The moon revolves about the earth once in something under 25 hours, and the earth having a circumference (in round numbers) of 25 thousand miles, the tide wave caused by the joint action of the sun and moon would, if the surface of our globe were uniformly and entirely covered with deep water, have a speed of 1000 miles per hour.† In mid-ocean, where there are no barriers to its progress, the tide wave is found to travel little short of this rate; but there is a rapid falling off in the speed as well as change in the direction, when the wave is obstructed by land stretching across its natural line of progress, also by the friction of the bottom in shoal water. For example, in the Southern Ocean the hourly rate is nearly 900 miles; in the middle of the North Atlantic, 520 miles; but in the Irish Channel, between Rathlin and the Isle of Man, the progressive rate of the wave of high water is only 50 miles per hour; and in the southern branch of the same, about half that amount. These speeds correspond respectively to depths of 9,150 fathoms, 3,000 fathoms, and 28 fathoms. When a free wave runs into shallow water it travels with less velocity, and its height is increased.

The relation of velocity to depth.

Let us remark in passing, that the tides with which our frequenters of the sea shore are acquainted are not the *direct* effect of the moon's attraction. They would seem to be more in the nature of a resulting incident. The tides are generated in the Great Southern Ocean, where they are *forced* oscillations, but those that we have in our part of the world are *free* oscillations, started. it is true, by the others, though running up to our latitudes on their own hook, under the action of terrestrial Gravitation. The

* *Inertia* is a purely negative property of matter. It is that inherent quality of passiveness in bodies which preserves them in a state of perpetual rest when undisturbed, or in perpetual motion unless arrested by some resisting force.

† See foot-note, page 396. The actual time taken by the moon to accomplish a revolution round the earth is 27d. 7h. 43m. 11½s. 24h. 50·6m. is the average interval in solar time between the moon's passing any given meridian and her return to same. It is made up of the earth's rotation on its own axis plus the moon's orbital motion just referred to

direct tidal effect of the moon in our seas is comparatively small, and is in many places antagonistic to the actual ebb and flow of the waters witnessed by our sea-side visitors.

The "equilibrium theory" assumes an ideal globe entirely covered with a frictionless ocean: but as our earth does not conform to this condition, and as the ocean is very far from being frictionless, the ideal tide is not the tide that we actually know. As a matter of fact, theory does not always represent the tides of the ports of the world. Observation shows that the irregular distribution of land and water, and the variable depth of the ocean, in themselves alone produce an irregularity in the oscillations of the sea of such complexity, that the rigorous solution of the problem is altogether beyond the power of analysis. Therefore, the tides of any given place cannot be predicted from a knowledge of the tides of any other place. Observations alone will do so, and in this form the problem is a simple one.

Ideal and actual tides

Here it is necessary to observe that, owing to fluid-friction, the *inertia* of the water, and other causes, the tide wave is found to lag behind the moon, and on this account the highest tides do not occur when her influence is greatest, but from one to three days after. The tide *corresponding* to New, or Full Moon, can however be detected by its superior height, which accordingly enables us to get at what is termed the *retard* or *age* of the tide. Its value is determined by taking the average interval between the moon's transit at F. and C. and the highest High Water following it.

Retard or age of the tide.

Similarly, High Water at any place is not simultaneous with the moon's passage of the meridian of that place, but mostly occurs an hour or two after; indeed in some places there is actually Low Water at the time of the moon's meridian passage: discrepancies are innumerable, and ports can be mentioned shewing all the intermediate phases. If H.W. everywhere, at Full and Change, corresponded exactly with the time of meridian passage, there would be only one "Establishment of the Port," namely, XII. hours; but the Tide Tables shew that this is very far from being the case.

Difference between tide *wave* and tide *current*.

At this stage of our subject it is most important to distinguish between the motion of a tide *wave* and that of a tide *current.*

The tide wave is due not nearly so much to the actual horizontal *transfer* of a body of water from one place to another, as to an *elevation* of its surface. Thus the sun and moon do not *draw after them* the mound of water which has been raised by their attraction, but are all the time engaged *in raising the water which is vertically beneath them.* As we have seen, the propagation of this tide *wave* is compatible with immense velocity, whereas the tide *current* rarely exceeds 5 or 6 miles an hour. Were the tide wave one of *translation*, like the tide current, it would carry destruction in its course. The peculiarity of its action may be shewn in this way:—

Form motion

Let two men stand a few yards apart, each holding the end of a piece of rope stretched loosely between them. Now, if one of the men were to shake the rope smartly in an up and down direction, he would cause undulations or waves in it, which would travel to the other end with great rapidity; nevertheless, from both ends being retained in the hands of the men, the rope, *taken as a whole*, would occupy throughout the same position.

The shaking of a sail, or the fluttering of a flag, serve to illustrate the same effect, therefore we see that it is the *form* alone of the wave which moves, and *not* the water of which it is composed. In other words, the same wave as it advances is not composed of the same water.

Propagation of light, heat, and sound.

Light, heat, and sound are transmitted in a similar manner. Let us take the latter by way of further illustration:—

If a long spar be gently tapped at one end, the blow will be readily heard by a person applying his ear to the other end. In this case the sound wave is propagated by the minute but rapid *vibrations* of the atoms of wood composing the spar, but no one for a moment would suppose that the identical *piece* of wood which was struck had travelled to the ear of the listener. Solids, generally, conduct sound much more rapidly than air. Oak, for example, will transmit it with exactly ten times greater velocity. Thus, in the experiment just mentioned, if the spar be struck with sufficient force, the listener will hear two distinct sounds, with an interval between them, depending upon the length of the spar, the first sound transmitted by the wood, and the second transmitted by the air. Iron is a still better conductor.

Waves of translation.

Recent investigation, however, goes to prove that every sea wave is *more or less* a wave of translation, setting down each particle of water, or of matter suspended in water, a *little* in advance of where it picked that particle up; but to the ordinary observer this transference of matter is so slight as to be imperceptible. By the seaman, however, it is taken into practical account when he is making allowance for "the heave of the sea."

Effect on waves of shoaling water.

Shoaling of the water makes a material difference in the character of a wave. Its base is then retarded by the increasing friction of the ascending bottom, and its leading side, in consequence, becomes steeper and steeper, until at length the crest outstrips the base, and, toppling over, breaks into foaming surf. This may be witnessed any day in the approach of waves to a shelving beach. Where the foreshore happens to slope very gradually, these breakers extend a proportionately long distance seaward; but in such cases the ground friction deprives them of their original height and energy long before reaching the beach. **Surf and breakers.**

The name has escaped the writer's memory, but there is a place on the Malabar coast where the water, for miles seaward, shoals so regularly and slowly over muddy bottom, that the force of the heavy seas during the S.W. monsoon is quite spent by the time they get near the land; knowing this, it is common for the small craft thereabouts to run in on what is a dead lee shore, and anchor without fear in 4 fathoms.

For conditions of an opposite character take the bar of the Tagus, which shoals *abruptly* from a depth of several hundreds of fathoms existing only a few miles to the westward. During winter gales the deep-water undulations come rolling in upon it in an unreduced form, and break with terrific violence. They have even been known to sweep the decks of large mail steamers that have rashly attempted to enter at such times, though the bar carries not less than 6 fathoms at low water (in the shoalest part). This would give the height of these formidable breakers as upwards of 30 feet, since it is generally accepted that the depth of water where the wave first breaks is equal to the height of its crest above the undisturbed sea level. **Rule as to height of breakers.**

To give an idea of where broken water will dash to in storms, it is related by the late Captain George Bayly (Elder Brother of the Trinity House), in an article entitled, *British pluck in the arts of peace*, that, "during the winter of 1861, the fog bell of the Bishop lighthouse—Isles of Scilly—secured to the stone gallery by a neck of solid metal four inches thick, at an elevation of 100 feet above H.W. mark, was carried away. A mountain wave reared its foaming crest many feet above the lantern, and as it swept past, snapped the solid neck like a carrot: the bell fell down on the rock beneath and was broken into pieces, some of which were afterwards picked up, and, together with the broken neck, were shewn amongst models and other articles from the Trinity House at the International Exhibition of 1862." The bell weighed several cwt., and after the storm the gallery was found thickly strewn with sand.

About the year 1886 the tower was raised upon, and its diameter considerably increased; the *additional* granite masonry weighed 2,950 tons!!

Piers and breakwaters—how constructed in present day.

Engineers have of late years taken advantage of the comparative absence of *horizontal* force in *unbroken* waves, to construct almost perpendicularly the sea faces of such piers or breakwaters as require to be built in exposed positions. Formerly, works of this character had a very long batter or slope, the effect of which—similar to that of a shelving beach—was to cause the waves to curl over and break in a manner which forced out huge blocks of stone, each very many tons in weight; and this undermining process went on until the solid masonry was completely breached through.

Properties of unbroken waves.

Again, it is not improbable that the reader has seen unbroken waves reflected back from a vertical sea wall; in which case he will have noticed that the reflected outgoing waves pass *through* the incoming ones, and each continues on its course almost as if nothing had happened. The principal visible effect produced by the collision is to momentarily increase the height of the waves at their point of meeting; but after a time the reflected wave is so reduced in speed and size by its repeated encounters with succeeding incoming ones, that it dwindles away, and at last ceases to exist; were they *solid* bodies undergoing translation, the wave with the greater momentum would overcome and carry with it the other one—but, of course, at a reduced speed.

Cape 'Nor-westers.'

To take another example: Every sailor knows that, when hove-to in a gale, his ship, if properly loaded and handled, will ordinarily ride over the monster seas like a duck; and it is clear that such could not be the case if each wave were hurled against the vessel as an independent and separate accumulation of water. But as soon as their free movement is interfered with by friction, no matter how produced, waves have a tendency to "top" and become vicious. For instance, on the edge of the Agulhas Bank, off the pitch of the Cape of Good Hope, it is well known that the seas generated by a W.N.W. gale are often opposed by a strong current setting right in the wind's eye. The result is a hollow, curling sea; and woe betide a deeply laden ship should she meet one of these ugly customers at an awkward moment.*

* Oil slowly dropped into the sea has a *wonderful* effect in preventing it breaking on board. It is common in some parts of England, before beaching a boat, to pull up and down for a few yards, pouring oil on the water, and then row in on the smooth.

The principal facts as to the use of oil are as follow:—

1. On free waves, *i.e.*, waves in deep water, the effect is greatest.

2. In a surf, or waves breaking on a bar, where a mass of liquid is in actual motion in

A weather tide in a river is an example of the same thing on a very much smaller scale.

From the foregoing we learn that a wave proper has but a trifling effect in the horizontal transference of floating objects, which do little more than rise and fall on its surface; but the same wave, when transformed into a "breaker" by friction, will carry all before it.

The "Bores" peculiar to rivers with expanded mouths are produced in a manner very similar to "breakers." As the Tide wave advances up the river, it is continually checked underneath, not only by the friction of the bottom, but by the resistance of the downward current. These causes operate to dam up the incoming tide, which is nevertheless pushed on by the ever-increasing volume of water behind, until it assumes a steep "Bores."

shallow water, the effect of the oil is uncertain; as nothing can prevent the larger waves from breaking under such circumstances; but even here it is of some service.

3. The heaviest and thickest oils are most effectual. Refined kerosene is of little use; crude petroleum is serviceable when nothing else is obtainable; but all animal and vegetable oils have great effect.

4. A small quantity of oil suffices, if applied in such a manner as to spread it to windward.

5. It is useful in a ship or boat, both when running or lying to, or in wearing.

6. No experiences are related of its use when hoisting a boat up in a sea-way at sea, but it is highly probable that much time and injury to the boat would be saved by its application on such occasions.

7. In cold water, the oil, being thickened by the lower temperature, and not being able to spread freely, will have its effect much reduced. This will vary with the description of oil used.

8. The best method of application in a ship at sea appears to be: hanging over the side, in such a manner as to be in the water, small canvas bags, capable of holding from one to two gallons of oil, such bags being pricked with a sail needle to facilitate leakage of the oil.

The position of these bags should vary with the circumstances. Running before the wind they should be hung on either bow—*e.g.*, from the cathead—and allowed to tow in the water.

With the wind on the quarter the effect seems to be less than in any other position, as the oil goes astern while the waves come up on the quarter.

Lying-to, the weather bow and another position farther aft seem the best places from which to hang the bags, with a sufficient length of line to draw to windward while the ship drifts.

9. Crossing a bar with a flood tide, oil poured overboard and allowed to float in ahead of the boat, which would follow with a bag towing astern, would appear to be the best plan. As before remarked, under these circumstances, the effect cannot be so much trusted.

On a bar with the ebb tide it would seem to be useless to try oil for the purpose of entering.

10. For boarding a wreck, it is recommended to pour oil overboard to windward of her before going alongside. The effect in this case must greatly depend upon the set of the current, and the circumstances of the depth of the water.

11. For a boat riding in bad weather from a sea anchor, it is recommended to fasten the bag to an endless line rove through a block on the sea anchor, by which means the oil is diffused well ahead of the boat, and the bag can be readily hauled on board for refilling if necessary.

broken front like a bubbling cascade, and constitutes one continuous breaker, having a long flat back. As the "bore" advances, it is hemmed in at the sides by a contracting channel, which forces it still more to rise above the ordinary level, since, if the form of the channel cannot accommodate the rush of water in one way, it must in another. It is not uncommon to see two or three smaller "bores" coming along on the back of the first.

Bore' not a wave.

The "Bore" cannot be accurately described as a wave. It is in no sense an undulation, nor is there any depression after it has passed: indeed, a rise in its wake of two to four feet of water is not unusual.

This phenomenon occurs mostly in rivers situated at the head of delta-shaped estuaries, and where these open broadly to the direct course of the Tidal wave, the effect is necessarily more marked.

In the Húgli, the "Bore" not infrequently appears as a liquid wall 6 or 7 feet high, and its noise is such that it is heard whilst yet several miles away. In the western branch of the Amazons it is said to have a front of 10 to 12 feet in height, and in its effort to find equilibrium, travels at the rate of 10 to 15 miles an hour, overcoming everything in its progress.

Chepstow, in the Bristol Channel; Mont St. Michel, in the Gulf of St. Malo; Dungeness Spit, near Cape Virgins; and the Basin of Mines, at the head of the Bay of Fundy,—are all places celebrated for a great Tidal Rise and Fall, which in extreme cases amounts at some of them to 70 feet and upwards. This unwonted augmentation of the height of the tide wave is simply due to the concentration of the energy of motion of a large body of water into a narrow space.

Tides in open ocean and inland seas.

On the other hand, in the open ocean, where the Tide wave is untrammelled, the range is but four feet or so, and in inland seas it is almost insensible. For instance, among the islands of the Pacific Ocean the Rise and Fall varies from 3 to 6 feet, and in the Mediterranean the average Rise and Fall does not exceed 18 inches, though in places—Sphax for example—owing to local causes, the Rise and Fall is fully five feet.

Lakes and inland seas being comparatively small, the attraction of the sun and moon is nearly equal at both extremities, therefore their tides are insignificant. Close investigation backs up the theory that the magnitude of the tidal range depends upon the proportion the size of the lake or sea bears to the diameter of the earth: for instance, the existence of a tide in Lake Michigan has been proved by a series of observations made at Chicago in 1859. The average height of this tide is 1¾ inches; and the average time of H. W. is 30 minutes after the moon's transit. The length of Lake Michigan is 350 miles, or $\frac{1}{23}$ of the earth's diameter; and its tide is about $\frac{1}{23}$ of that which prevails in mid-ocean. Again, the length of the Mediterranean is 2,400 miles, or, roughly, ⅓ the diameter of the earth, which gives the average height of its tide as ⅓ what it is in the open sea, and this is confirmed by observation.

Tide *current*.

The Tide Current, then, is caused by Tide waves from the ocean being concentrated and checked by local formation, also by the frictional resistance offered by the bottom and sides of a narrow channel. In passing through contracted spaces, these waves, as already stated, are heaped up and urged on by the continued pressure of the water behind, whose motion is less retarded than that of their own; and thus, in seeking to find its level, an actual current is created.

***Ocean* currents**

The *Tide* Current must not, however, be mixed up with the general *Ocean* Currents, which are progressive movements of the water, due partly to *prevailing winds*, and partly to *differences of temperature and density*, which, by disturbing the equilibrium, cause a constant circulation to be going on in the waters of the globe; and this, be it remembered, takes place in a vertical as well as a horizontal direction.

Effect on tides of river improvements.

It is difficult at first to realize that mere friction can play such an important part in connection with tidal currents, but unmistakable evidence of this is given in a variety of ways. For example, of late years the Tyne has been improved by straightening some of the worst bends, and by dredging its bed. The result is that High Water now occurs at Newcastle some 20 minutes or so earlier than it did previous to these improvements, though the distance from Tynemouth to Newcastle is but 9 miles or thereabouts.

The Tide hour* has been accelerated at Glasgow by similar means, and also at London Bridge, but in a less degree.

Offing and inshore tides

Again, most seamen—especially coasters—are aware that the stream of the tide runs longer in the offing than close alongshore. Two causes operate in producing this effect. From the water being deeper in mid-channel, its motion is proportionately less retarded by bottom friction; whilst the littoral current—affected in a much greater degree by bottom and side friction—

* More generally termed "Establishment of the Port."

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has, moreover, to penetrate the bights and follow the bends of the coast. Reference to the accompanying co-tidal map of the British Islands will shew this feature very plainly; it will be noticed more especially in the English Channel, and in the contracted portion of the northern branch of the Irish Channel.*

Co-tidal map.

The Tide current sometimes continues to flow in the offing for three hours after it has turned by the shore, and is then termed "Tide and half tide"; and "Tide and quarter tide" when it only runs for 1½ hours longer. Moreover, the time *at which the stream turns* is often different at different distances from the shore, *but the time of High Water is not necessarily different at these points.* This same peculiarity may be observed in a small way in the Mersey and other rivers, where, though the stream may still be running up in mid-river, it will be at a stand inshore, and the water-level will have fallen several inches at the pier-heads.

Tide and Half Tide.

A knowledge of this difference in the turn of the inshore and offshore streams is of great service, more particularly in working to windward, since by keeping close in at the commencement of the tide, and standing out mid-channel towards the last of it, it is possible to carry a favouring tide for nine hours. Indeed, in a smart vessel, *navigated by a man with good local knowledge,* the *flood* may be carried even longer: and in a steamer—from the fact of the turn of the tide in certain cases getting progressively later—the ebb may at times be cheated altogether.

Carrying the Flood up Channel.

For example:—Neglecting the odd minutes, it is High Water, Full and Change, at Queenstown at 5 o'clock, and at the Bar Lightship, Liverpool, at 11 o'clock. Now, if on such a day a 17-knot steamer were to leave Queenstown at noon, with the young flood or eastern tide, and round the Tuskar closely, she would carry the tide with her the whole way to the Lightship, a distance of about 226 miles. It should be stated, however, that between Roche's Point and the Coningbeg lightvessel the stream is weak, even at springs. Owing to a peculiarity, which will be alluded to further on, a ship passing through the Straits of Dover, bound to a port on the East Coast, and hitting the tide at the right time, will carry it for nearly twelve hours. The same thing can also happen in the George's Channel.

* Lines connecting all those places which have high water at the same instant of *absolute* time are termed Co-tidal lines. They are useful as marking the progress of the Tide *wave* hour by hour, and are generally drawn for Greenwich Mean Time. They have no reference whatever to Tidal *current.* The map here shewn is taken from a pamphlet by the Rev. Samuel Haughton, M.A.

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We now come to another very important phase in the phenomena of tides. It is of the greatest consequence to the navigator that he should not confound the *Rise* and *Fall* of the tides with the *Flow* and *Ebb*. **Rise and Fall as distinguished from Flow and Ebb**

It is too generally supposed that at High Water the flood *current* ceases, and similarly, of course, that at Low Water the ebb *current* ceases; in other words, that the *flood* stream only runs whilst the water is *rising*, and that the *ebb* stream only runs whilst the water is *falling*. Now this is not by any means a necessary consequence; and so far from its being even *generally* the case, such a condition is proved to be extremely rare, and then only to be found in small bays and harbours.

The supposed cessation of the Flood and Ebb streams at High and Low Water respectively, is unfortunately a very prevalent, but at the same time not unnatural, misconception, and has doubtless contributed to many a disaster.

Owing to the momentum of the water, which does not permit of its onward motion ceasing simultaneously with the exciting cause, and owing sometimes to *difference of level*, it is not uncommon to find the Flood run for three hours *after the water has commenced to fall;* and, similarly, the Ebb may continue running out for three hours *after the water has commenced to rise.** Thus, at the actual times of High and Low Water, the Flood and Ebb streams respectively, instead of being "slack," may, on the contrary, be running with their greatest velocity.

This peculiarity is shewn in a very striking manner at the First Narrows, or eastern entrance to the Strait of Magellan, where it is due almost entirely to excessive difference of water level. **Tides in narrow inlets.**

As already stated, in small harbours and bays slack current takes place at the "stand" of the tide at High and Low Water, but where the tide wave enters a narrow inlet, connecting with a great inland basin, the case is different. The basin being nearly tideless, has its surface lying at about the *mean sea level;* therefore, Flood currents can only commence to run in through the Narrows when the surface of the outside water has risen above that of the basin, and the maximum velocity must occur at High Water for the Flood, and at Low Water for the Ebb.

* Most people who have to do with the docking and undocking of vessels will have noticed, by tide-gauges or marks of some sort, how a river rises or "swells" long before the last of the Ebb stream, showing that the Tide *wave* may be going one way, when the *water* itself is actually going another.

Tides in Strait of Magellan.

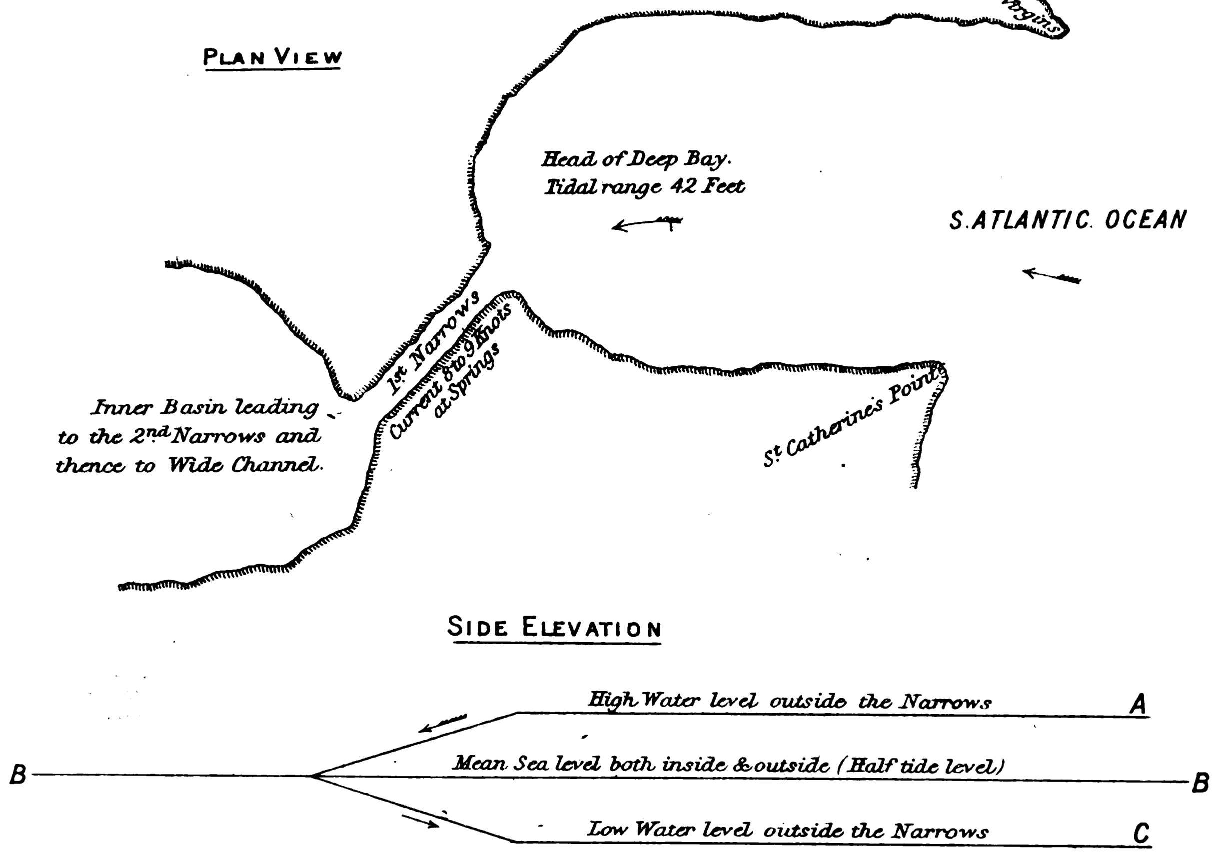
This is precisely what happens in the Strait of Magellan—which, though not an inland sea in the strict sense of the term, nevertheless partakes sufficiently of the characteristics of one. Now, it so happens that, in the gourd-shaped arm of the sea adjoining the contracted cliffy channel forming the water communication between the Strait and the South Atlantic, there is a Rise and Fall of 42 feet. This great tidal range is due to its shape, combined with the fact that it opens invitingly to the direct course of the tide-wave flowing in from the South Eastward. But, in the basin immediately within the Narrows, the range is only 22 feet, and further on it is much less; for, when a large water area has to be filled through a contracted opening, as in the present case, the inner tide suffers a gradual *degradation* as the water composing it spreads itself, and finally becomes nearly insensible; therefore it is that, after passing what is known as the Second Narrows, the Magellan tide virtually becomes spent, and the Rise and Fall insignificant: indeed, the latter would be even less were it not for the numerous water passages communicating with the Pacific Ocean, which act as feeders.

What has been here described as occurring *inside* the Narrows is just the reverse of what takes place *outside* the Narrows. In the latter case the tidal range is continually *augmented* as it proceeds up the estuary, till at or near the head it reaches its maximum.

The annexed diagrams are intended to illustrate the action of the tides at the Eastern entrance to Magellan Strait, and in them we have taken the liberty of supposing the basin on the left to have no Rise or Fall whatever; this is not consistent with the actual fact, but it simplifies the explanation without in any way detracting from the truth of the general principle referred to in the text. The upper diagram does not profess to be anything more than a *very rough* outline of the entrance to Magellan Strait, nor is it even drawn to scale. (See *Diagram No.* 5).

We will begin by supposing it high water outside the Narrows, as represented by the line *A*. The water will then commence to fall; but from its level being 21 feet higher than inside, the flood stream will continue to run in through the Narrows till both basin and estuary have arrived at the same level, which will not happen, however, for 3 hours, by which time it will be half Ebb. The ocean water which has passed through the Narrows cannot, however, do much to swell the inner tide, since its volume is but trifling as compared with the large area over which it has to spread itself. At 3 hours after high water, the surface level being then the same both inside

Diagram No. 5



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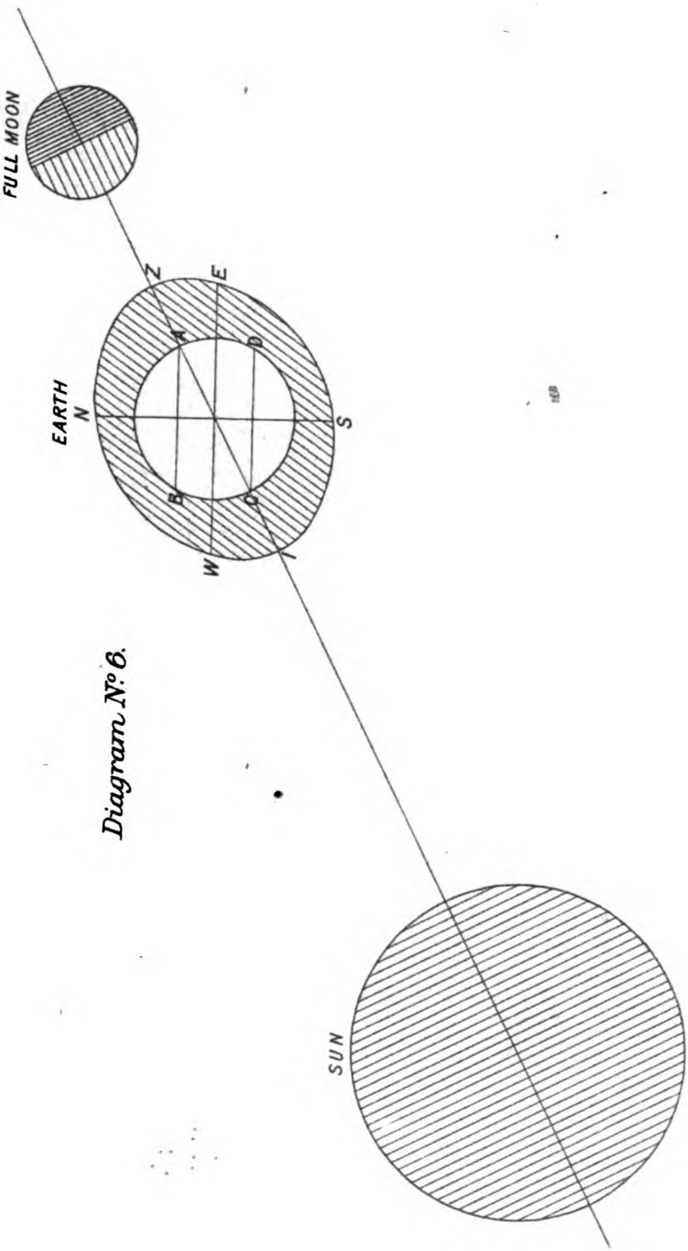

Diagram No. 6.

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and out, there is a *momentary* stand in the current, which, up till now, has been flowing in; but, as soon as the outside level drops sufficiently to cause an incline in the other direction, the stream will commence to rush *out*, and continue to do so till the common level is again restored, which will not be before half flood. As may well be imagined, the tide in the Narrows seethes like a boiling pot, and makes steady steering an impossibility.

Generally, in considering the tides of estuaries, it is found that the interval from High to Low Water is longer than from Low to High Water, and the difference between the intervals is greater at Springs than at Neaps. At St. Heliers, Jersey, the mean duration of Ebb and Flood at Springs is seven and five hours respectively. Also, as we ascend rivers, so the interval from Low to High Water diminishes. At Oceanic ports the intervals are about equal.

DIURNAL INEQUALITY.

Popular idea as to Night Tides being higher than Day ones.

Another popular but erroneous notion is, that the night tides are always higher than the day ones.

Pilots are very prone to this idea, and, without investigation of any kind, it is passed along from father to son as a sort of professional legacy. The *real facts* are as follows:—

In consequence of what is called the Diurnal (or daily) Inequality, it sometimes happens that the night tides are higher than the day tides for weeks together; but if such be the case at one period of the year, the day tides are higher at another.

Declinational tide.

Prolonged and properly conducted observations prove conclusively that the height of the tide at a given place is influenced by the *Declination* of the moon; for, as the tide wave ever tries to place its highest point vertically under the body which produces it, when this vertical changes its point of incidence on the surface of our globe, the tide wave must tend to shift with it; thus, when the moon's declination is 0°, the highest tides should occur along the Equator, and the heights should diminish thence towards the North and South; but, other things remaining as before, the two consecutive tides at any place should have the same height. (*See Diagram No.* 6.)

Diurnal inequality.

When the moon has north declination, as shewn in the diagram, the highest tides on the side of the earth next the moon will be at places having a corresponding north latitude, as at *A*; and on the opposite side of the earth from the moon, at those which have an equal south latitude, as at *C*. And of the two consecutive tides at any place, that which occurs when the moon is nearest the zenith should be the greater. Hence when the moon's declination is *North*, the height of the tide at a place in north latitude should be greater when the moon is *above* the horizon, as at *A*, than when she is below it, as at *B*. On the same day, places *South* of the equator have the highest tides when the moon is *below* their horizon, and the least when she is above it. A careful study of the diagram will make this apparent.

In continuation, let us suppose the moon to be "Full," and her declination 28° North. At midnight, therefore, she will be in the *zenith* of a place at *A*, in north latitude, and will produce a *high* night tide. At *D*, situated on exactly the same meridian, but in south latitude, the midnight tide occurring at the same absolute instant of time as the first-named will be a *poor* one, as the *moon's altitude there is low.* On the other side of the globe, the places *B* and *C* have high water at their *noon*, simultaneously with *A* and *D* at their *midnight;* but *C* being in the direct line of the moon's attraction, has much the higher tide of the two.

Night tides not *always* the highest.

From these considerations it is obvious that the Inferior or day tide at *C* must be greater than the Superior or night tide at *D*, which completely upsets the idea that "Night tides are *always* the highest."

To put the matter in another way:—When not on the equator, the moon's zenith distance at upper transit is different from her nadir distance at lower transit, but the tide-generating force is greater the smaller the zenith or nadir distance, and, therefore, the forces are different at successive transits. Thus there is a tendency for two successive lunar tides to be of unequal heights: this tendency vanishes when the moon is on the equator, and as this latter occurs each fortnight, the *lunar* diurnal tide is evanescent once a fortnight.

Similarly, at the solstices in summer and winter, the successive *solar* tides are generally of unequal height, whilst in spring and autumn, when the sun is on the equator, this difference vanishes.

Constant complications.

In this connection there is yet another little complication. In consequence of the variability of the inclination of the lunar orbit to the equator, the heights of the various purely *lunar* tides are variable from year to year. The tide computer has no special difficulty in determining the effects due to each of these causes.

To go from theory to facts, take for instance what happens at Whampoa docks. In March the day and night tides rise to the same level. From April to October *the day tides are the higher*, and from November to February the lower. At San Francisco, a rock which has three and a half feet water upon it at one Low Water, may be awash at the next succeeding Low Water; but when the moon is on the Equator, the inequality at this port disappears, and the day and night tides become equal.

The Diurnal Inequality varies greatly in amount at different places, but it follows fixed laws at each, and may be predicted

It sometimes becomes so large that for several days there is only one tide in 24 hours: this latter phenomenon is very common on the S.E. coast of China, the coasts of California and Oregon, and in the Gulf of Mexico. On the coasts of Great Britain and Ireland the Diurnal Inequality is small.

This important factor affects the *time* as well as the *height.* For example, at Aden, Karachi, Bombay, and other Indian ports, the times of H.W. may be accelerated or retarded occasionally as much as two hours.

METEOROLOGICAL TIDES.

But apart from the irregularities just alluded to, there are two circumstances which affect the height of the tide, and also the times of high and low water. These are the force and direction of the wind, and the height of the barometer. Thus, at Liverpool, a S.W. gale both augments the tide and prolongs it, whilst a blow from the opposite quarter invariably retards and "cuts" it. Weather effects.

A rise or fall of an inch in the barometer is attended with a corresponding fall or rise in the tide, varying from 6 to 20 inches, according to situation. At Liverpool it would be equal to 12 inches, which is nearly in the same ratio as the specific gravities of mercury and water.

As these two last influences cannot possibly be predicted in the Almanacs, the tabular times and heights are sometimes considerably in error; indeed, wind has been known to increase the height of a tide as much as 5 feet.

We now pass on to what are termed "Interferences" due to configuration of the coast, a meeting together of two or more channels, or the obstruction of islands. These "Interferences" occur on both a grand and a small scale. By their action it may happen that two distinct sets of tide waves will produce apparent rest; this rest sometimes takes the form of height, sometimes of time, and sometimes of both. When complications of this kind occur, they require most careful and lengthened investigation before they can be traced back to their true sources. Interferences

At Southampton there is a double High Water, the second occurring within two hours of the first. The fall in the interval does not amount to more than 9 inches, although the Rise and Fall between High and Low Water is 13 feet. The main features of this peculiarity are thus explained:— Tidal peculiarity at Southampton.

The *inshore* eastern or flood stream runs past the Needles into the Solent, and makes High Water at Southampton in the orthodox manner. The tide then falls a little with the last of the stream; but when it turns to the westward inshore, a great body of water, favoured by the shape of the land, unites with the last of the *outside* eastern stream, still flowing round the south-eastern part of the island, and *both* run into the back of the Wight, by way of Spithead. Now, the outlet for it between Hurst Point and the Needles being much smaller than the eastern channel by which it entered, the returning water gets pent up, and, in consequence, there is a general rise in the Solent. At Calshot Castle the tide forks—one branch going out by the Needles, and the other flowing up Southampton Water, which lies open like a trap in the direct course of the main current, and so causes a *second* High Water. This is succeeded by a uniform but rapid fall, lasting about 3½ hours.

Favoured Southampton.

To the mariner the knowledge that the High Water at Southampton remains nearly stationary for rather more than two hours, may, in some cases, be important.

The influence of the double H.W. is felt to the westward as far as Swanage, but along the coast it can scarcely be attributed to the same cause as that within the Isle of Wight, but rather to a levelling northward of the water from the direction of the French coast, where, immediately opposite this part, the rise of tide is 16 or 17 feet, as compared with the 6 or 7 feet on the English shore.

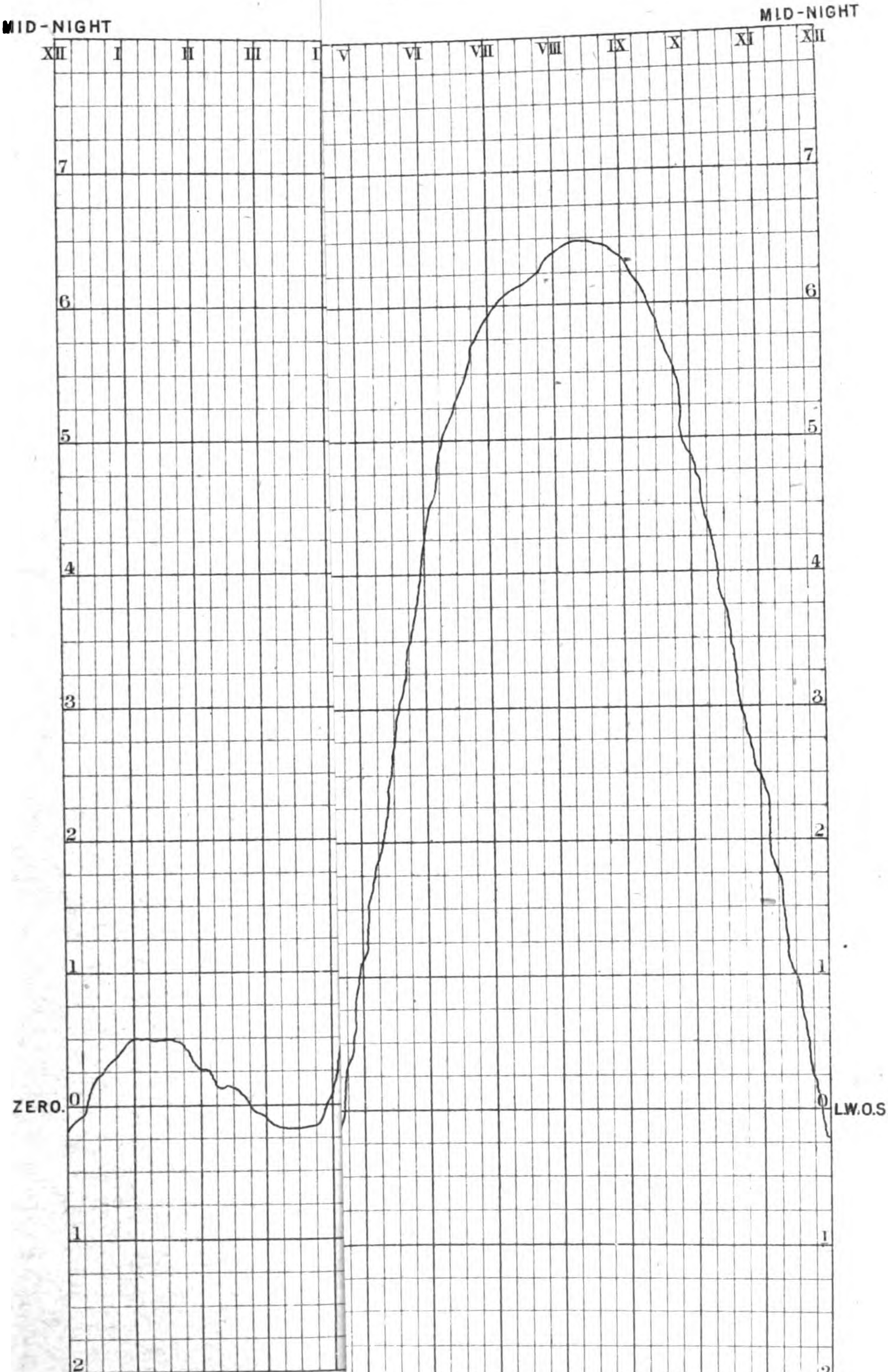
Tidal peculiarity at Havre.

At Havre, on the north coast of France, though the spring rise is 22 feet, the "stand" at High Water lasts one hour, with a rise and fall of 3 or 4 inches for another hour, and only rises and falls 13 inches for the space of three hours. This long period of nearly slack water is very valuable to the traffic of the port, and permits a larger number of vessels to enter or leave the docks on the same tides than would otherwise be the case.

The 'Gulder.'

At Weymouth (Dorset), only 55 miles from Southampton, there is, on the contrary, a double Low Water. What happens, therefore, is just the reverse of the Southampton phenomenon, and, as if this were not enough, it lasts twice as long. The cause is not well understood, though a shot at it is made on page 155 of the Admiralty Tide Tables.

The ordinary spring range is about 7 feet, and at the Equinoxes about 8½ feet. From one H.W. to the next, there is the usual 12½-hour interval; this is divided into three equal parts, namely, a steady fall for 4 hours, L.W. for 4 hours, and a steady rise for 4 hours. The diagram facing this page is a *fac-simile* (on a



The numerals at th... s of the Tide-gauge in feet and quarters.

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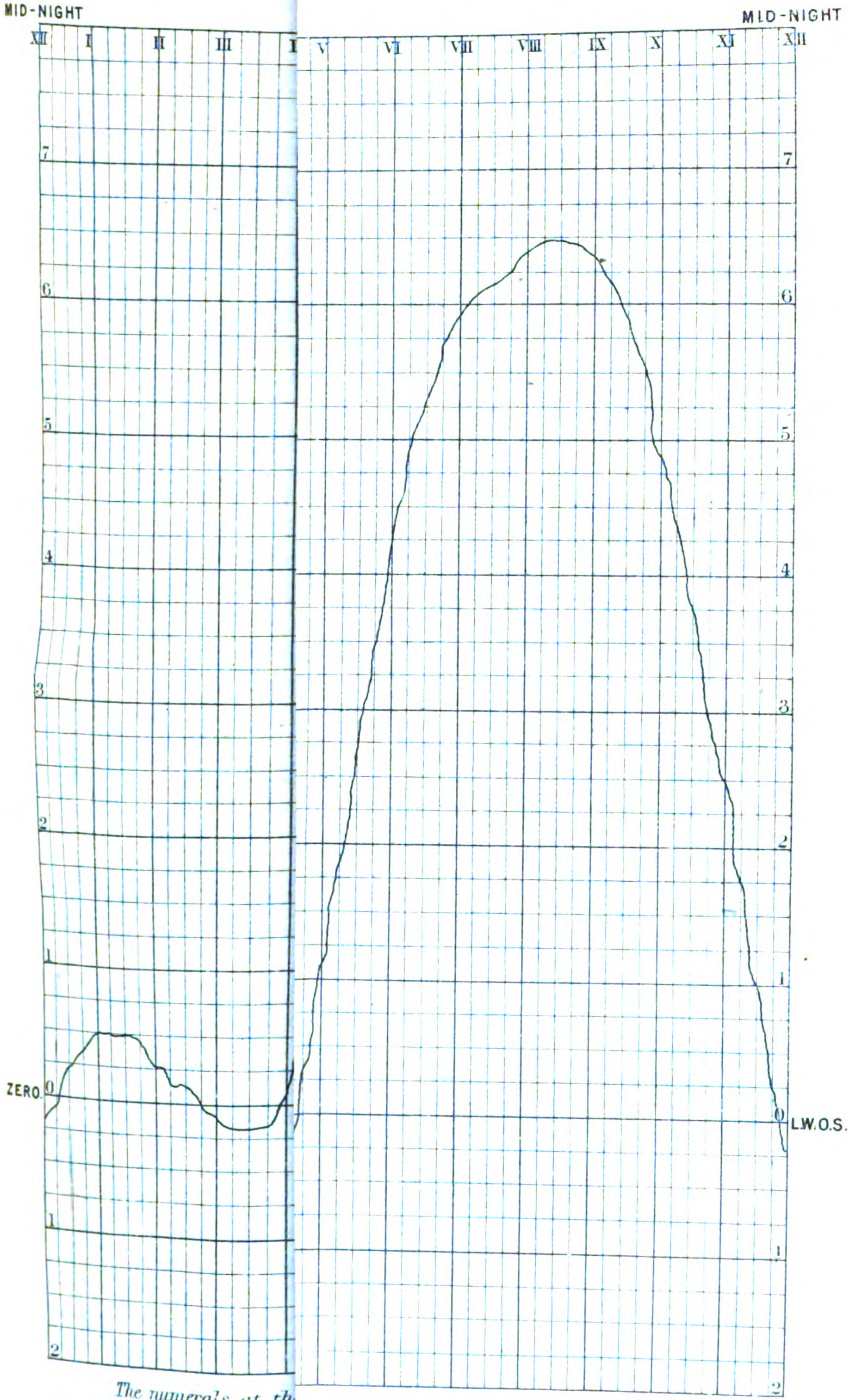

The numerals at th   *ns of the Tide-gauge in feet and quarters.*

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reduced scale) of one actually taken from the self-registering tide-gauge in use by the Weymouth Corporation. It shews the tide trace for one whole day, and includes two High and two Low Waters.

Weymouth at a disadvantage.

It is interesting to notice in each case that, shortly after the tide has fallen to L.W., it turns slowly upwards for nearly two hours, and as slowly falls again during the next two hours. Then the real rise commences and continues to H.W.

This curious undulation during L.W. is locally known as the "Gulder," and though it rarely exceeds six inches, the effect—unless masked by atmospheric influences—is well marked and regular. At Springs it is much more apparent than at Neaps. Practically speaking, therefore, L.W. at Weymouth continues for 4 hours, and in the case of vessels over 12 feet draft, materially adds to the difficulty of their navigation. Perhaps this is compensated by the excellent shelter procurable during westerly gales.

The tides, then, are not all plain sailing, as might be supposed; and it would be almost impossible for any one man to make himself acquainted with the peculiarities of those on our own coasts alone, unless, indeed, he had no other employment.

There is one feature which must not be trifled with: fortunately the localities affected by it are well known. Near the headlands separating bays there is usually at certain times of tide a swift and turbulent current termed a 'race.' When opposed by a strong wind the sea breaks badly, and in gales—especially at Springs—deeply-laden brigs, schooners, and other small fry not infrequently founder with all hands. These 'races' are due to conflicting currents, accentuated by the passage of the water over foul bottom, causing 'rips' and 'overfalls' in which small craft cannot live. Even large vessels get battered about, and their decks swept.

Standard Port of reference for English Channel tides.

For the direction and rate of the tide in the Channel at any given time or place, the navigator must consult the Admiralty Sailing Directions and Tide Tables. In the latter, the English Channel and North Sea are divided into compartments, in which the Magnetic direction and rate of the tidal streams is given *for every hour of the tide at Dover*. The tables for the Irish Sea are less elaborate, but they contain, nevertheless, much valuable information.

Although in these pages it would be impossible to enter into details, a few words may be said about the general rules which govern the main system of tides round about our shores.

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Direction taken by Tidal Wave round Great Britain and Ireland.

Reference to the Co-tidal Map facing page 284 will shew that the tide wave coming in from the Atlantic splits on the west coast of Ireland. One part, going northward, sweeps round by Inishtrahul and the Giant's Causeway, and enters the George's Channel between Rathlin Island and the Mull of Cantyre; the other part, going to the southward round Cape Clear, enters the same channel between Tuskar and St. David's Head. These streams pursue their respective courses till they meet at the "Head of Tide," which is upon an imaginary line drawn from Dundrum Bay through the Isle of Man, towards Barrow-in-Furness. At the junction of the two tides occurs, as may be expected, the greatest rise and fall, amounting to 15 feet on the Irish side, and double that amount on the English.

"Head of Tide" in Irish Channel.

To the *westward* of the Isle of Man we find an "Interference. The two streams, flowing in exactly contrary directions, here destroy each other, so that no current is at any time perceptible, and the bottom of this region of still water is characterized by a deposit of fine blue mud.

To the *eastward* of the Isle of Man the tidal currents meet at an angle, and flow on together with increased vigour towards Morecambe Bay and Liverpool, making High Water at these places seven hours after its occurrence at their point of separation near the Skelligs.

Offshoots of this same parent tide wave enter the English Channel and German Ocean, the latter coming round "north about." These two tide waves bring High Water to the south and east coasts of England respectively, and also, like those in the Irish Channel, have a place of meeting, or "Head of Tide," which for *them* is found in the Straits of Dover.

"Head of Tide" in English Channel.

An investigation of the tidal streams of the Irish Sea, by the late Admiral W. F. Beechey, R.N., brings to light the important fact that, notwithstanding the variety of times of High Water throughout it, *the turn of the stream over all that part which may be called the fair navigable portion of the Channel, is nearly simultaneous.*

Standard Port of reference for Irish Channel tides.

The northern and southern streams in both branches of the Channel commence and end *in all the fairway parts* at nearly the same time; and that time corresponds closely with the time of High and Low Water on the shore *at the entrance* of Liverpool and of Morecambe. So that it is necessary only to know the times of High and Low Water at either of these places, to determine the hour when the stream of either tide will commence or terminate in any part of the Channel, *outside the influence of the inshore eddies.* For this purpose the Liverpool Tide Tables may be used, subtracting 18 minutes from the times there given, in consequence of H.W. at George's Pierhead being that much later than the point which is considered the "Head of Tide."

Now, since it is low water at Queenstown at the same time that it is high water at Liverpool, it follows that midway between the two there must be a place of comparatively little Rise and Fall: and this in the South channel is found to be on a line joining Courtown and Cardigan Bay, and in the North channel on a line joining Fairhead and the Mull of Cantyre. These are termed the "Nodal points," and here it is that the greatest body of water passes, and the tidal *currents* are strongest.

"Nodal Points" for Irish Channel tides.

There are similar effects produced in the English Channel. Careful experiments, systematically carried out by Admiral Beechey and Captain Bullock, R.N., prove that the *channel* streams meeting and separating in Dover Strait, set uniformly in a direction *towards* Dover whilst the water is *rising* at that place, and *away from it* when it is *falling.* To be governed by this law, a vessel must be either in that portion of the channel situated between Beachy Head and a line joining the Start with the Casquets, or between the North Foreland and a line joining the Texel with the Humber.

Off the mouth of the English Channel, *westward* of a line joining Ushant and Scilly, the stream will be found running to the *northward and eastward* while the water is *falling* at Dover, and to the *southward and westward* while it is *rising* at that port.

In the intermediate section included between a line joining Ushant and Scilly, and another joining the Start and the Casquets, there is a *mixed* tide, partaking of the joint directions of the tides east and west of it, which renders a written description impossible; and the Admiralty Tide Tables alone must be consulted for the direction and rate at any particular hour.

The nodal points of the two channel streams meeting in Dover Strait are respectively at Swanage and Yarmouth.

"Nodal Points" for English Channel tides.

Several other important and interesting features remain to be noticed. The Ebb stream of the Irish and English Channels constitutes the *Flood* of the Bristol Channel; and the Flood of the Irish and English Channels constitute the *Ebb* of the Bristol Channel: so that, within a line joining Scilly and Tuskar, the

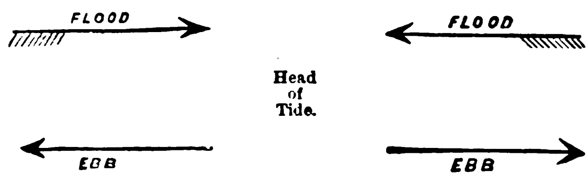
Comparison of English, Irish, and Bristol Channel tides.

tide will be found running eastward towards the Bristol Channel whilst the water is *falling* at Liverpool and Dover, and running out from the Bristol Channel whilst it is *rising* at those places. On its northern side, the Bristol Channel flood sets to the South-eastward, and on its southern side to the North-eastward. It is handy to recollect, also, that when it is High Water at Liverpool and Dover, it is approximately Low Water at Cardiff and Queenstown.

Carrying the Tide for 12 hours.

A few pages back it was stated that a vessel navigating the English and Irish Channels might, if she were lucky, carry the tide with her for nearly 12 hours. To show how this could happen, it is necessary to recollect that, at the Head of Tide, the streams meet and separate thus :—

Dover Strait.



Consequently, if a vessel happens to reach the Head of Tide with the last of the Flood, she will forthwith run into the *opposite* Ebb stream just beginning at that point, and so continue with a favouring tide during the next 6 hours.

Such is a rough outline of the main features of the tides on our coasts; but, for the more detailed information necessary to the safety of a ship working up or down channel in dirty weather, the navigator is referred to the Admiralty publications already alluded to—from which sources the foregoing summary of channel tides has been chiefly compiled.

Particulars concerning Admiralty Tide List.

The Admiralty List* furnishes the Times and Heights of High Water for the morning and afternoon of *every day in the year*, at a number of standard home ports, including Brest. By aid of a Table of *Tidal Constants*, adapted to certain standard ports, of reference, the approximate times and heights of high water *for every day in the year* can readily be found for many British, Irish, and European ports, extending as far as Heligoland on the north, and Gibraltar on the south. And, to finish up, the same valuable work gives the time of High Water at *Full and Change*, with the Rise at Springs and Neaps, for no fewer than 3,300 of

* Published annually.

the principal places on the globe. These last form two distinct tables—one being arranged alphabetically, and the other according to the apparent progress of the Tide Wave.

The tide-producing influences being the same for each, the time of High Water varies for different ports in the same vicinity, owing to the inertia of the water, and the obstruction it meets with from the configuration of the sea bed, and the narrowness, length, and direction of the channels along which the wave has to travel before reaching the port. It is obviously of great maritime importance to be able to find on any day the time of High Water for the various harbours and ports of the world, and to this end a *standard tide* is fixed upon, indicated by a particular relative position of the moon and sun, from which the time of every succeeding tide may in most cases be deduced.

Establishment of the Port.

This standard is spoken of in general terms as the "Establishment of the Port." But there are various "Establishments," and various definitions, so one is apt to get "mixed." Unfortunately even the best writers are at variance when it comes to detail. If any leading authority like Lord Kelvin would only clear away the points of divergence, he would indeed be additionally a benefactor. Meanwhile the reader can take the following on trust:

By "Establishment," whether "Vulgar," "Corrected," or "Mean," must be understood a certain *interval of mean time*, and not in the first instance an hour of the day by any particular clock.

***Vulgar* Establishment of the Port.**

The "Vulgar Establishment" may be defined as the actual time of H.W. after *apparent noon* of the day upon which the moon passes the meridian *at the same instant as the sun*. It is evident that this conjunction can happen only very rarely, so the more convenient plan is resorted to of taking the average interval between the moon's transit on the day of F. and C. and the succeeding H.W.

It is found, however, that in general any particular tide is not due to the moon's transit immediately preceding, but to a transit which has occurred a considerable time before, and which is therefore said to *correspond* to it. This accounts for the highest tides of springs not occurring at time of Full and Change, but from one to three days after. This it is which gives rise to the appropriate expression "Age of the tide."

***Corrected* Establishment of the Port.**

The "Corrected Establishment of the Port" is the average interval between the time of the moon's transit and the time of H.W. on that particular day which *corresponds* to Full and Change, and may differ considerably from the "Vulgar Establishment."

The "Mean Establishment"—used in the United States of

America—is approximately determined by noting each day, for one or more complete lunations, the interval between the moon's transit and succeeding High Water, and taking the mean of them. These are termed *lunitidal intervals*, and the difference between the greatest and least is termed the *semi-mensual* or *semi-monthly inequality of Times*. This inequality, unfortunately, is not the same for each place; hence the time of High Water at any place cannot always be *accurately* deduced from that at any other place, by merely applying the difference of time between their Establishments.

Semi-mensual inequality of *Times*.

The "Mean Establishment" is always less than the "Vulgar Establishment."

Semi-mensual inequality of *Heights*.

In like manner the *semi-mensual inequality of Heights* forbids the height of the tide at any one place being *correctly* inferred from the given height at any other.

Owing to this *semi-mensual inequality* being often large—sometimes exceeding two hours—the time of High Water, *as deduced from the Vulgar Establishment*, is open to serious error: it is therefore to be regretted that, from insufficient data, the Admiralty List does not give the Corrected Establishment for *every* port mentioned, nor indeed does it always specify which is which.

This, however, is a defect which, as our tidal knowledge of out-of-the-way places becomes more complete, will be more or less rectified each succeeding year. In the meantime, it may generally be accepted that the Tide Hour of *all* the principal ports, at home and abroad, is represented in the list either by the Corrected or by the Mean Establishment.

The expression "Tide Hour" was first introduced by Raper, and was intended by him to supersede the other and more obscure phrase; it has not, however, been adopted, but in any case would equally require accurate definition.

Where the tides are pretty regular, which is mostly, though not always, the case round our own coasts, the table on next page may come in useful when it is required to know the depth of water over a rock, bar, or bank, at some particular hour of the tide.

How to estimate Tidal Rise for the day.

If the Rise for the day is not exactly known, it may be inferred from the Spring and Neap Rise given on the chart. For instance, if the Mean Spring Rise at Devonport Dockyard is 15½ feet, and the Neap Rise 12 feet, one might fairly assume the Rise midway between Springs and Neaps to be about 13¾ feet.

From this can be deduced the Range for the day as follows:—

	FT.	IN.	FT.	IN.
Mean Spring Range or Rise	15	6		
Assumed Rise for the day	13	9	13	9
Difference	1	9	1	9
Assumed Rise − Diff. = Range for the day			12	0

The following Table shews approximately the movement of the tide (in feet and decimals) at 20^m intervals for any range not exceeding 50 feet. It will be noticed that the movement is greatest at half-tide. For example, with a 50-foot range the rise or fall of the water in 20^m at half-tide is 52 inches, but only 5 inches at 20^m from High or Low Water.

Range is measured from L.W. of any given tide to the following H.W.

Tidal Range for the day in feet.	TIME OF TIDE BEFORE OR AFTER HIGH WATER.																			Tidal Range for the day in feet.
	0h.			1h.			2h.			3h.			4h.			5h.			6h.	
	m. 0	m. 20	m. 40	m. 0	m. 20	m. 40	m. 0	m. 20	m. 40	m. 0	m. 20	m. 40	m. 0	m. 20	m. 40	m. 0	m. 20	m. 40	m. 0	
2	2.0	2.0	1.9	1.9	1.8	1.6	1.5	1.3	1.2	1.0	0.8	0.7	0.5	0.4	0.2	0.1	0.1	0.0	0	2
4	4.0	4.0	3.9	3.7	3.5	3.3	3.0	2.7	2.3	2.0	1.7	1.3	1.0	0.7	0.5	0.3	0.1	0.0	0	4
6	6.0	6.0	5.8	5.6	5.3	4.9	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.1	0.7	0.4	0.2	0.0	0	6
8	8.0	7.9	7.8	7.5	7.1	6.6	6.0	5.4	4.7	4.0	3.3	2.6	2.0	1.5	0.9	0.5	0.2	0.1	0	8
10	10.0	9.9	9.7	9.3	8.9	8.2	7.5	6.7	5.9	5.0	4.1	3.3	2.5	1.8	1.1	0.7	0.3	0.1	0	10
12	12.0	11.9	11.6	11.2	10.6	9.9	9.0	8.1	7.0	6.0	5.0	3.9	3.0	2.1	1.4	0.8	0.4	0.1	0	12
14	14.0	13.9	13.6	13.1	12.4	11.5	10.5	9.4	8.2	7.0	5.8	4.6	3.5	2.5	1.6	0.9	0.4	0.1	0	14
16	16.0	15.9	15.5	14.9	14.1	13.1	12.0	10.7	9.4	8.0	6.6	5.3	4.0	2.9	1.9	1.1	0.5	0.1	0	16
18	18.0	17.9	17.5	16.8	15.9	14.8	13.5	12.1	10.6	9.0	7.4	5.9	4.5	3.2	2.1	1.2	0.6	0.1	0	18
20	20.0	19.8	19.4	18.7	17.7	16.4	15.0	13.4	11.7	10.0	8.3	6.6	5.0	3.6	2.3	1.3	0.6	0.2	0	20
22	22.0	21.8	21.3	20.5	19.4	18.1	16.5	14.8	12.9	11.0	9.1	7.2	5.5	3.9	2.6	1.5	0.7	0.2	0	22
24	24.0	23.8	23.3	22.4	21.2	19.7	18.0	16.1	14.1	12.0	9.9	7.9	6.0	4.3	2.8	1.6	0.7	0.2	0	24
26	26.0	25.8	25.2	24.3	23.0	21.4	19.5	17.4	15.3	13.0	10.7	8.6	6.5	4.6	3.0	1.7	0.8	0.2	0	26
28	28.0	27.8	27.2	26.1	24.7	23.0	21.0	18.8	16.4	14.0	11.6	9.2	7.0	5.0	3.3	1.9	0.8	0.2	0	28
30	30.0	29.8	29.1	28.0	26.5	24.6	22.5	20.1	17.6	15.0	12.4	9.9	7.5	5.4	3.5	2.0	0.9	0.2	0	30
32	32.0	31.8	31.0	29.9	28.3	26.3	24.0	21.5	18.8	16.0	13.2	10.5	8.0	5.7	3.7	2.1	1.0	0.2	0	32
34	34.0	33.7	33.0	31.7	30.0	27.9	25.5	22.8	20.0	17.0	14.0	11.2	8.5	6.1	4.0	2.3	1.0	0.3	0	34
36	36.0	35.7	34.9	33.6	31.8	29.6	27.0	24.2	21.1	18.0	14.9	11.8	9.0	6.4	4.2	2.4	1.1	0.3	0	36
38	38.0	37.7	36.9	35.5	33.6	31.2	28.5	25.5	22.3	19.0	15.7	12.5	9.5	6.8	4.4	2.5	1.1	0.3	0	38
40	40.0	39.7	38.8	37.3	35.3	32.9	30.0	26.8	23.5	20.0	16.5	13.2	10.0	7.1	4.7	2.7	1.2	0.3	0	40
42	42.0	41.7	40.7	39.2	37.1	34.5	31.5	28.2	24.6	21.0	17.4	13.8	10.5	7.5	4.9	2.8	1.3	0.3	0	42
44	44.0	43.7	42.7	41.1	38.9	36.1	33.0	29.5	25.8	22.0	18.2	14.5	11.0	7.9	5.1	2.9	1.3	0.3	0	44
46	46.0	45.7	44.6	42.9	40.6	37.8	34.5	30.9	27.0	23.0	19.0	15.1	11.5	8.2	5.4	3.1	1.4	0.3	0	46
48	48.0	47.6	46.5	44.6	42.4	39.4	36.0	32.0	28.2	24.0	19.8	15.8	12.0	8.6	5.6	3.2	1.4	0.4	0	48
50	50.0	49.6	48.5	46.7	44.1	41.1	37.5	33.6	29.3	25.0	20.7	16.4	12.5	8.9	5.9	3.3	1.5	0.4	0	50

The range for the day is to be sought for in either side column, and the required quantity will be found on the same horizontal line under the given time from High Water.—The table is only suitable to such places as have regular tides.

To see how the Table will compare with the one (B) in the Admiralty list, which is specially drawn up for use with the heights given in its own columns, we will create and work out an example or two by both methods.

The Pollock Rock, in Hamoaze (Plymouth Sound), has 18 feet on it at Mean Low Water Ordinary Springs: What depth will

Depth of Water over a rock at any given time of Tide.

there be over it on the 9th of December, 1881, at 2h. 10m. after High Water in the afternoon?

	FT.	IN.
Entering the Table with 12 feet as the assumed Range for the day, and 2h. 10m. after H.W., we find by interpolation	8	6½
Depth on the rock at L.W.O.S.	18	0
Diff. between M.S.R. and Rise for the day	1	9
Depth over the rock on December 9th, at 2h. 10m. after H.W.	28	3½

According to Admiralty Tables.

	FT.	IN.
Height of Tide above the mean level of L.W.O.S., by the Tables (page 90) December 9th, 1881	13	9
Half Mean Spring Range (given at foot of same column)	7	9
Height of H.W. above half tide or mean level of the sea, *December 9th*	6	0

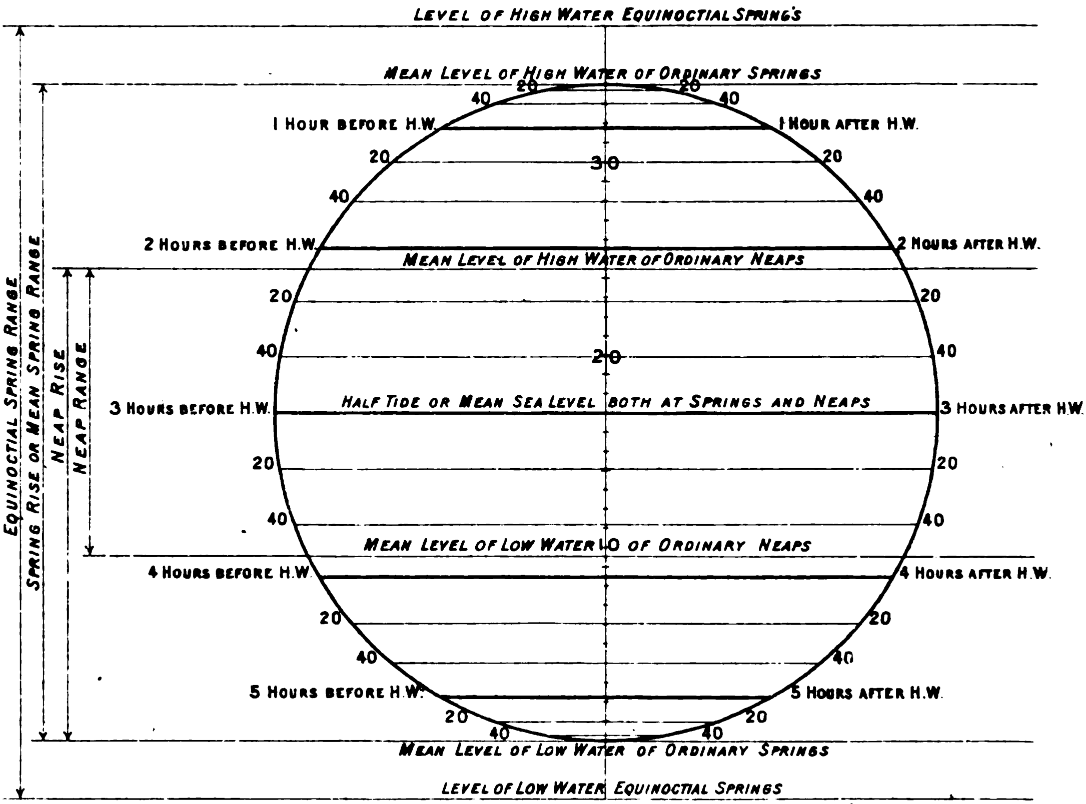
	FT.	IN.
Half Mean Spring Range	7	9
By Table (B), 6ft. 0in. and 2h. 10m. give	2	6
Depth on the Rock at L.W.O.S., as per chart	18	0
Depth over the Rock on December 9th, at 2h. 10m. after H.W.	28	3

In this example the difference is only half an inch, which is not worth talking about. Let us take another, where the datum line for soundings is the low water level of *Equinoctial Springs.*

Example when the Plane of Reference is below the level of L.W.O.S.

According to Admiralty Plan No. 2011, the Stag Rock in Holyhead Bay carries 13 feet over it at Low Water. The same plan contains a notice that "the soundings are reduced to an Equinoctial Spring Tide of 20 feet, which is about 2 feet lower than the Ordinary Low Water Springs." What depth will there be over the rock on the 10th December, 1881, at 1h. 40m. before H.W. in the afternoon? The plan gives the *Mean* Spring Rise as 16 feet, and the Neap Rise as 12½ feet; accordingly, the rise in Holyhead Bay on the day in question may be assumed as 14¼ feet above the level of Mean Low Water *Ordinary* Springs. This would give 12½ feet as the range for the day.

	FT.	IN.
Entering the Table with 12½ feet as the assumed range for the day, and 1h. 40m. before H.W., we find	10	3
Depth over the Rock at L.W., Equinoctial Springs	13	0
Equinoctial Springs lower than *Ordinary* Springs	2	0
Diff. between M.S.R. and rise for the day	1	9
Depth over the Stag Rock on December 10th, at 1h. 40m. before H.W.	27	0



SPRING RANGE 34 FEET. NEAP RANGE 15 FEET. EQUINOCTIAL SPRING RANGE 40 FEET.

SCALE, $\frac{1}{10}$ OF AN INCH = 1 FOOT

TO FACE PAGE 299

According to Admiralty Tables.

	FT.	IN.
Height of H.W. by the Tables (page 95) above the mean level of L.W. Ordinary Springs, December 10th, in the afternoon - - - -	14	3
Half Mean Spring Range - - - - - - - - - - -	8	0
Height of H.W. above Half-Tide or Mean Sea Level, December 10th -	6	3

	FT.	IN.
Half Mean Spring Range - - - - - - - - - - -	8	0
By Table (B), 6ft. 3in. and 1h. 40m. give - - - - - - - -	8	1·1
Depth over the rock at L.W. Equinoctial Springs, per chart - - -	18	0
Equinoctial Springs lower than *Ordinary* Springs - - - - - -	2	0
Depth over the Stag Rock on December 10th, at 1h. 40m. before H.W. -	26	11

What will be the depth over the Stag Rock at Mean Low Water Ordinary Springs, Mean Low Water Ordinary Neaps, and Low Water of Equinoctial Springs? The plan gives the neap range as 9 feet. Work these out by way of practice, and if you do it correctly the answers will be,—

	FT.	IN.
Depth over the Stag Rock at Mean Low Water, Ordinary Neaps	18	6
" " " " " " Springs	15	0
" " " " " Equinoctial "	13	0

The diagram facing this page shews the graphic method by which the preceding Tidal Table is constructed. It is given here in preference to the method by calculation, which last is not nearly so instructive. **Construction of Table.**

As Practice is better than Precept, the actual mode of constructing the diagram will be explained. Draw a vertical line in the centre of the paper to do duty as a tide-gauge. Let its length represent 34 feet, which we will suppose is the Mean Spring Rise or Range. For the sake of accuracy, choose a fairly large scale for your diagram, say ¼ of an inch to the foot, but should your range be small, the scale can be increased with advantage; it might be taken at one inch to the foot, which permits reading to single inches with ease. But for the purpose of this illustration we must be content with only $\frac{1}{10}$th of an inch, being restricted by the size of the page. Adopting this scale, the vertical line will be exactly 3·4 inches high. Lay along it an ordinary boxwood or ivory plotting scale (marked decimally), and beginning at the bottom, divide the line into tenths of an inch, each one of which will of course represent a foot. Then from 17 feet as a centre, describe a circle with a radius of 1·7 inches. Divide the right and left hand semicircles each into 18 parts, by stepping round them with a pair of spring dividers. These 18 parts will represent hours and thirds of an hour between High and Low Water; the duration of a tide being taken in round numbers as 6 hours, which in practice is sufficient. Name them as shewn in the diagram.

Diagram will shew depth at any hour

Connect similar intervals on each side by parallel horizontal lines; where these lines cut the tide-gauge, will be found the height corresponding to the time from H.W. For instance, the line indicating 4 hrs. 20 m. before or after H.W. cuts the gauge at 6·1, which accordingly would in this case be the depth above your plane of reference (Mean Low Water of Ordinary Springs) at that particular time of tide.

Suppose, further, that on the day in question H.W. happened at 7.20 P.M., then, subtracting from this 4 hrs. 20 m., you would have 6·1 on the gauge at 3 P.M. (tide rising); and again the same water about midnight (tide falling).

To complete the Table, a circle must of course be drawn for each range.

In the diagram here given, let it be understood that the lines outside of the circle—above, below, and to the left—have nothing whatever to do with the construction of the Table. They are merely introduced to assist the Admiralty diagram on page 272 in explaining the various terms employed in connection with tidal movements.

Rise must not be confounded with *Range*. Rise is measured from the zero of the gauge, which zero is, or ought to be, set to mean L.W.O.S., whereas Range is the amount of the vertical movement of *any* given tide, whether at Springs or Neaps. Inspection of the diagram will shew, however, that these terms correspond in the case of H.W.O.S.

For convenience of measuring specially low tides, the gauges are generally continued downwards for a few feet below zero. Readings taken of this portion are of course marked minus.

Influence of tides in retarding the rotatory motion of the earth.

In a foot-note to page 396, some slight reference is made to the frictional effect of the tides in retarding the rotatory motion of the earth. The writer thinks that, by way of a fit conclusion to this chapter, he cannot do better than quote Professor P. G. Tait on this interesting subject.* Speaking of Lord Kelvin's reasoning as to the probable age of the earth, he goes on to say:—

"The second of these arguments of Lord Kelvin depends upon

* See page 170, *et sequitur*, of *Recent Advances in Physical Science*. By P. G. Tait. Macmillan & Co.

the tidal retardation. In my first lecture I mentioned to you that there was such an effect, and that it had been actually observed by astronomers in a very peculiar way; because, on calculating back from the known present motion of the moon, it was found that there must be some unrecognised peculiarity in that motion which had not been deduced by calculations founded upon gravitation, either as attraction or as disturbance. The moon, in fact, seems to have been moving quicker as time has gone on, since the eclipses of the fifth and eighth centuries before our era. The only way, as Laplace puts it, in which it could be accounted for in his time, was by what he called 'secular acceleration of the moon's mean motion.' In other words, the average angular velocity with which the moon moves round the earth appears to have been increasing for the last 2,000 years or more. He shewed that there was a mode of accounting for this by planetary disturbance of the earth's orbit; and, as calculated by him, this explanation seemed to account for exactly the amount of acceleration which was observed in the moon's motion. Using his formulæ, and the numbers calculated from them, and working back to those old days, we find we arrive at almost the circumstances of those eclipses, as described by historians.

Laplace's investigation

"Fortunately, Adams, a few years ago, revised Laplace's investigation, and found that he had neglected a portion of the necessary terms, and that the explanation given by Laplace, when properly corrected, accounted for only one-half of the phenomena observed; so that there still remained one-half of the quantity to be accounted for. This could not be accounted for by the disturbance of other bodies attracting the moon. Why, then, does the moon appear, every revolution, to be moving faster and faster round the earth? Well, the only way in which we can explain it, after we have made every possible allowance for effects of disturbance by other planets, is simply to enquire—Does our measure of time continue the same?

Professor Adams' revision and discovery.

"We measure the time of the moon's revolution in terms of hours, minutes, and seconds; but these hours, minutes, and seconds are measured for us not by our clocks, as you may at first think. We set our clocks by the earth's rotation, and, therefore, it is in terms of the earth's rotation that we measure the time of the moon's revolution round the earth. So that the moon will appear to be moving quicker round the earth, even supposing her orbit be altogether undisturbed, if the earth itself, which is furnishing the unit of time in which her revolution is to be measured, is rotating slower and slower from age to age.

Newton's first law of motion.

"Then comes the question, Is there a cause which tends to slacken the earth's rotation? Newton laid it down, in his first law of motion, that motion unresisted remains uniform for ever; and referred to the earth as a particular instance, where there is nothing in the attraction of the sun or moon, or the disturbance caused by any of the other planets, affecting the rate of its rotation about its axis.

"But it was left to Kant, first of all, to point out, and even to approximate in amount to, a resistance to the earth's rotation, due to the tide-wave; and to shew that the earth—because the tide-wave is lifted up towards the moon, and on the opposite side from the moon—has constantly to rotate inside what is practically a friction-brake. The water is held back by the attraction of the sun and moon, and the earth has to move inside this shell of water. There is, therefore, a source of constant friction, and friction, of course, constantly produces development of heat. The heat must be accounted for by some energy transformed, and what is here transformed is part of the energy of the earth's rotation about its axis. So long as tides go on, there will therefore be constantly a retardation of the rate of the earth's rotation.

"Now, let us see when this relaxation of the earth's rotation would cease. Obviously this would be at the instant when the earth at last ceased to rotate within the tide-wave; in other words, when the tide-wave rotates along with the earth—when it is always full tide at one and the same portion of the earth's surface—the tide-wave being fixed (as it were) upon the earth's surface. But the tide-wave is always, approximately at least, directed towards the moon, so this part of the surface where the tide-wave is fixed for ever must be constantly turned towards the moon. In other words—if there were no sun-producing tides, but the moon only, the final effect of the tides, in stopping or quenching the earth's rotation, would be to bring the earth constantly to turn the same portion of its surface towards the moon, and therefore to rotate about its axis in the same period as that in which the moon revolves about it. This most remarkable ultimate effect we see already produced in the moon,—it is precisely the same thing,—we see the moon turning almost exactly the same portion of its surface to the earth at all times. The little deviation we see occasionally is precisely accounted for by the fact that the moon's orbit is not exactly a circle, and therefore the moon does not move in it with the same rapidity when

Moon turns but once on its axis whilst making a single revolution round the earth.

it is nearest the earth as it does when it is furthest away from the earth. We are thus, as it were, enabled occasionally to see a little round the corner. The moon is now rotating precisely in the way in which the earth will in time rotate, when as much as possible of its energy of rotation is used up in producing heat by tidal friction. And that the moon should already have come into this state so long before the earth has arrived at it, need not surprise us. The moon's seas (when she had them) were of molten lava,—far more viscous than water; and the tide-raising force on her surface depended on the mass of the earth, some *eighty* times greater than that of the moon, which is the main agent in our comparatively puny tides.

"It being thus established that the rate of rotation of the earth is constantly becoming slower, the question comes: How long ago must it have solidified in order that it might have the particular amount of polar flattening which it shews at present? Suppose, for instance, that it had not consolidated less than a thousand million years ago. Calculation shews us that at that time, on the most moderate computation, it must have been rotating at least twice as fast as it is now rotating. That is to say, the day must have been 12 hours long instead of 24. Now, if that had been the case, and the earth still fluid without, or even pasty, that double rate of rotation would have produced four times as great centrifugal force at the equator as at present, and the flattening of the earth at the poles and the bulging at the equator would both have been much greater than we find them to be.

Deduction as to age of the earth.

"We say, then, that because the earth is so little flattened, it must have been rotating at very nearly the same rate as it is now rotating when it became solid. Therefore, as its rate of rotation is undoubtedly becoming slower and slower, it cannot have been many millions of years back when it became solid, else it would have solidified into something very much flatter than we find it. That argument, taken along with the first one, probably reduces the possible period which can be allowed to geologists to something less than ten millions of years."

A new theory of the tides has recently been broached by the Rev. J. H. S. Moxly, in a paper read at the Royal United Service Institution; and his views, together with careful criticisms by Captain J. Ruthven, of the Orient Line, and Mr. E. Plumstead, will be found set forth in back numbers of the *Nautical Magazine* for 1900 and 1901.

CHAPTER XVIII.

FOG AND FLOATING ICE.

Retention of moisture in air.

It has been scientifically demonstrated that the air is capable of taking up a certain amount of moisture, and of retaining it suspended in a perfectly invisible gaseous state. As a matter of fact, the ordinary atmospheric air we breathe contains at all times more or less water so suspended. The higher the temperature of the air, the greater its capacity for the retention of water in this invisible form.

Steam—what it is.

Steam, which is nothing more than water at a high temperature, and in a gaseous state, is quite invisible so long as it remains as such; but the moment it comes into contact with anything cold, it gets more or less condensed, and shews itself as a white vapour, to which the late Dr. Tyndall gave the suggestive name of *water-dust.*

Glass model of engine and boiler.

This fact is strikingly illustrated by a working model of an engine and boiler, both made of glass, in which, although the water is seen to boil, *no steam is visible,* and the engine moves apparently without cause. After passing through various parts, the steam finally enters the condenser, where it is at once chilled and rendered visible by a jet of cold water.

"Dew-point."

When air, whatever may be its temperature, is fully saturated with water, and will hold no more, it is said to be at the "Dew-point." Now, this point being reached, if the temperature be lowered in any way, the moisture loses its aëriform character, and is condensed into white vapour, termed cloud when high in the heavens, and mist or fog when near the earth's surface.

The sea is the great *distillery* or place from which water is drawn up invisibly, in its purest state, into the air; and this is chiefly the case in the seas of the tropics, because there the sun shines with most power all the year round, sending a constant succession of heat-waves to shake the water-particles asunder. It has been found by experiment that, in order to turn 1 lb. of water into vapour, as much heat must be used as is required to melt 5 lbs. of iron; and if one considers for a moment how difficult iron is to melt, and how an iron poker can be kept in the fire and yet remain solid, it helps to realize how much heat the sun must pour down in order to carry off such a continuous supply of vapour as that which afterwards appears to us as rain, cloud, or fog.

This last-mentioned result, so very embarrassing at sea, is produced in a variety of ways, and not infrequently—strange though it may appear at first thought—by quite opposite conditions, which, however, it will be seen, are obedient to the same law. Thus, when warm air saturated to the "Dew-point" passes over cold water, the temperature of the air is reduced, its moisture is condensed, and fog is the consequence. On the other hand, when a cold wind blows over relatively warm water, the invisible vapour rising from the water is chilled, with precisely the same result. We have a familiar example of this latter mode of fog production each time we take a hot bath, and may notice how, in cold weather, much more vapour *appears* to rise from the water. When a deep ocean current is opposed by a shoal—such, for example, as the Banks of Newfoundland—the cold water from below is driven to the surface; and should it happen to be under the "Dew-point" of the air, fog is the inevitable result.

Fog—how produced.

Another cause of fog is the interlacing of currents of greatly varying temperatures, such as are often to be met with where the Gulf Stream and the Labrador Current meet. Lastly, it must be borne in mind that a bank of fog may be drifted by the wind to a considerable distance from where it was originated, and encountered by the mariner at a spot where there is little or no difference between the temperatures of the air and surface water; but such fogs rarely last long.

Drift Fog.

Much has been done by various maritime governments to modify the difficulties which fog presents to navigation. There are a few, however, which can only be overcome by great vigilance on the part of the mariner himself. Some fogs—probably when the water is colder than the air—have a tendency to lie in a thin stratum, which extends but 30 or 40 feet above the surface. In such cases it is quite possible to see over it by ascending to the masthead, from which position we may discern land, icebergs, or the masts of other vessels, when they are quite concealed to those on deck. Attention should therefore be paid to this point when sailing in fog. On the other hand, there are fogs which do not assume any great density until they have attained several feet of

Low-lying fog.

CHAPTER XVIII.

FOG AND FLOATING ICE.

It has been scientifically demonstrated that the air is capable of taking up a certain amount of moisture, and of retaining it suspended in a perfectly invisible gaseous state. As a matter of fact, the ordinary atmospheric air we breathe contains at all times more or less water so suspended. The higher the temperature of the air, the greater its capacity for the retention of water in this invisible form.

Retention of moisture in air.

Steam—what it is.

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Low-lying fog.

elevation; in which case, of course, it is advisable to get as low down as possible, when objects near the surface, such as rocks and hulls of vessels, may be made out at a distance of half a mile or more.

Fog-beset coasts—how navigated.

Some coasts are particularly exposed at certain seasons of the year to visitations of fog. This is markedly the case along the coasts of Chili and Peru. But where the water is very deep close up to the shore, and, consequently, the lead next to useless, there are frequently high cliffs, and the coasting captains running between ports only a short distance apart, have no hesitation in cautiously approaching them at very slow speed, knowing that with a good look-out either the roar of the surf, the "booming" of the waves against the cliffs, or the echo of the steam-whistle will be heard in sufficient time to warn of danger. Indeed, sometimes, after groping carefully along, it is only by the cessation of sound shewing a break in the coast-line, that it is known that the vessel has reached the entrance of the port. Of course such things were only done in small-paddle boats, by men who, so to speak, knew every foot of the coast, and were well acquainted with the speed of the vessels they commanded.

Signs indicative of approach to weather shore.

The approach to the eastern coast of Patagonia, which is a weather shore, is frequently notified by the strong smell of the wood and turf fires kindled by the natives. Although in *this* instance the lead *is* a reliable guide, owing to the moderate depth and gradual shoaling of the water, *which also gets smoother under the lee of the land;* in like manner, during a hazy night, the writer on one occasion was apprised of his near approach to an island of the Cape Verde group (Santa Lucia) by the Trade-wind coming down to him richly laden with the scent of the orange groves. The setting in or cessation of a ground swell, or a change in the colour of the water, will sometimes notify as to whether the ship is on or off soundings. Round our own coasts there are numerous well-known and strongly-marked tide races, such as those off Portland and South Stack (Holyhead), which have often proved a good guide in thick weather.

All these are indications which the navigator with his senses about him will be fully alive to; while a dull man will let them go by unnoticed, and possibly come to grief in consequence.

Coasting rule for thick weather.

In the home coasting trade the rule is—"See everything as you pass it;" and this is clearly the right thing to do when the weather is not so thick as to prevent objects being made out in ample time to avoid them, and when the nature of the shore admits of its being made free with, since it is dangerous to *play* with edge-tools. Take care, however, that a *really* good look-out is kept, *and the lead never out of hand.* By obeying this old-fashioned rule, the navigator is able to verify his reckoning from time to time, and get a fresh departure—a matter of no small value where tides run strongly, and it is important to gain a port at a certain time. Should this be neglected in narrow waters, and the fog shut down for a "full due," it is more than probable, in seeking to give danger a wide berth on one side, you will run into it on the other.

Lead not to be neglected.

When thick fog has lasted some little time in a channel beset with shoals and swift-running tides of great range—such, for example, as the Bristol Channel—the best of navigators is apt to lose the run of his position. In such cases the wisest plan is to *anchor* while there is plenty of water under the vessel's keel. It is sure to clear up before it comes on to blow with any force.

Advisability anchoring in fog

At any other time of anchoring than Low Water, *do not forget to allow for the fall of the tide.* In the eastern entrance of Magellan Strait, for example, where the rise and fall is 46 feet, and in the Bay of Fundy, where it is yet greater, it would not do to bring up at high water in less than eleven or twelve fathoms.

Southern-going vessels bound down channel, with a fair wind, will gain little or nothing by hugging the shore in thick weather. All *they* require is to shape a *mid-channel* course, keep the lead going, and get out to sea as soon as possible. Again, there is no excuse for a man who gets his ship ashore by running close alongside a nearly straight coast for hundreds of miles without being required to call at any port, and with open water all the time on the other side of him. It is necessary to discriminate in these matters. What is proper and necessary in the one case, may be a foolhardy risk in another.

A high rate of speed in a fog cannot be justified by any process of reasoning whatsoever. Attempts have often been made to do it; but none of the arguments brought forward will hold water: and he who runs blindly on at such times, especially when near land, and trusting solely to that "stupid old pilot" Dead-Reckoning, is culpable in the highest degree. With proper precautions and slow speed, vessels can be navigated in a fog with a close approximation to absolute safety, so far as the risk of getting on shore is concerned; but there will always be the danger of collision with another vessel, which is even more to be feared.

High speed in fog unjustifiable.

Within the past few years many of the more prominent headlands and turning points have been marked by the establishment of fog signals, such as guns, steam-trumpets, or sirens, and explosive rockets; while less important shoals have been indicated by automatic signal buoys, set in operation by the action of the waves. All these are of the greatest possible service.

Fog signals—various kinds of.

On one occasion the writer left Liverpool in a dense fog, being guided to the Crosby and Bar lightships by the steam-trumpets with which these vessels are fitted. The Skerries were rounded at a distance of three miles in the same manner, the blast of the steam-trumpet being audible at double that distance; and when off Holyhead, the reflection of the flash of the fog-gun was distinctly and repeatedly seen in the sky at an elevation of about 30°; this permitted its bearing to be taken, and by listening for the report, and counting by chronometer the number of seconds (twenty) which elapsed, the ship's position was fixed equally as well as cross-bearings could have done it in clear weather. For such observations it is sufficiently correct to allow 5 sec. per mile as the velocity of sound. Of course the lead was kept going unremittingly, and when the depth rendered the hand-lead useless, even more accurate casts were obtained with Lord Kelvin's invaluable sounding-machine.

Example of fog navigation.

It is important to know that sound is conveyed in a very capricious way through the atmosphere. Apart from wind or *visible obstructions*, large areas of silence have been found in different directions and at different distances from the origin of a sound, *even in the very clearest of weather*, and under a sky absolutely cloudless. The subject has been very fully investigated by no less a person than Professor Tyndall, aided by some of the Elder Brethren and officers of the Trinity House.

Atmospheric obstruction of sound.

Briefly, it was discovered that sound is liable to be intercepted by streams of air unequally heated and unequally saturated with moisture—in fact, by a want of homogeneity in the interposed atmosphere. Under such conditions, the intercepted vibrations are weakened by repeated reflections, and possibly may fail to reach the ear of persons well within the ordinary hearing limits. The experiments clearly proved that rain, hail, snow, and fog have no power to obstruct sound. Indeed, it was shewn that the condition of the air associated with fog is actually favourable to the transmission of sound.

Therefore, whilst the mariner may usually expect to hear a fog-signal normally both as to intensity and place, he should take the foregoing into account, and be prepared for occasional aberrations in audition.

It is found that, when approaching a fog-signal from to-windward, he should go aloft; and when approaching it from to-leeward, the nearer he can get to the surface of the water the sooner it will be heard. The apparatus, moreover, for sounding the signal, frequently requires some time before it is in readiness to act. Again, a fog often creeps imperceptibly towards the land —especially at night—and is not noticed by the people at the lighthouse or signal station until it is upon them: whereas, an approaching ship may have been for many hours in it, and those on board, knowing the admirable organisation and discipline of the lighthouse service, may be unwittingly standing into danger through relying upon hearing in good time the warning signal. Result, shipwreck: verdict, 'master to blame *for not using the lead.*'

Approach to ice not indicated by sea surface temperature

Allied to fog is the question of danger from ice. It is a popular delusion among passengers on board ship that, by taking the temperature of the sea surface at short intervals, the approach to ice is unfailingly indicated. Unfortunately, such is by no means the fact, and reliance thereon invites disaster. More than ordinarily cold water merely shews that the ship is in a part of the ocean where ice may possibly be encountered, and not that it is actually present.

The well-known Labrador Current, for example, is a cold stream flowing from Polar regions, and carrying with it, during spring and summer, enormous quantities of field-ice and bergs, which come down from Davis Strait. It is not the extra polar-ice, however, which causes the cold current, although it is the cold current which brings down the ice; consequently, the experienced navigators of the North Atlantic know full well when the sea surface temperature falls markedly to the eastward of the Banks that it is necessary to be more especially on guard against meeting ice.

By kind permission, and on the unexceptional authority of Captains Ballantine, Dutton, and Smith, of the Allan Mail Steamship Line, all men of high standing in the profession, and well acquainted with ice navigation, it is here stated that no appreciable difference in the temperature of the sea surface is caused by the proximity of even the largest icebergs; and, when one considers what a poor conductor of heat water is, their statement can be well believed.

This is very fully corroborated by the experience of Capt. G. M. Lourison, of the ship *Eaton Hall*, who, in March, 1893, fell in with quite a number of very large bergs in lat. 49° S., and long. 52° W. (See *Nautical Magazine* for July, 1893.) Though close to, *the bergs caused no effect whatever.*

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Law of convection.

In conformity with what is known as the law of convection, water will transmit heat readily enough in a *vertical* direction. Thus when the liquid in the bottom of a vessel is warmed by fire, it becomes specifically *lighter*, and accordingly *rises* and makes room for the colder surface water to flow down and fill its place; this cold water gets heated in turn, and so continually ascending and descending *currents* are created, until the temperature of every part alike is raised to the boiling point. The propagation of heat in a *lateral* direction does not take place in this manner at all. Heat spreads sideways in water by *conduction* alone, a process which involves no transference of the particles, and is very slow indeed as compared with the other.

Propagation of heat in a lateral direction.

For example, the axis of the Gulf Stream in some parts is made up of bands of warm water which alternate with cold ones, but, although running side by side, they do not commingle. Further, the separation between the deep blue waters of the Gulf Stream and the cold counter-current which runs down in-shore, is often so well defined, that a ship may be sailing in both at the same moment. From its being so steep-sided, the inner current, at line of meeting with the Gulf Stream, has received the name of "Cold Wall," and has been known to differ 30° in temperature from the one running close alongside it.

"Cold wall."

On the other hand, if the Arctic Current points to a region where ice may be expected, it by no means follows that it will not be encountered in the Gulf Stream, as bergs have been passed not only *in* the stream, but actually to the southward of it, having been carried there by the *lower* ocean currents. The possibility of this will be recognized when it is stated as a matter of certainty that icebergs are seldom submerged to a less extent than $\frac{7}{8}$ of their whole mass, and oftentimes much more. Thus a cube-shaped berg 15 fathoms high would ordinarily ground in 100 fathoms of water. This measurement is readily derived from the relative specific gravities of fresh and salt water, and the fact that the volume of water is increased 9 per cent. when freezing. With the Barometer at 30 in. and Fahrenheit's Thermometer at 62°, a cubic foot of ordinary sea water weighs 64·00 lbs., a cubic foot of fresh water 62·36 lbs., and at 32° a cubic foot of ice weighs 57·50 lbs.

Icebergs—submersion of.

Temperature is an important element in this calculation, as it causes the density both of water and ice to vary considerably; thus the *specific gravity* of fresh water is greatest at 39°·2 Fahr., and ice reaches its maximum *volume* at 24° Fahr., *below which* *it contracts.* It is capable of proof that, from this cause, ice at 16° Fahr. *will sink* in water of 50° Fahr.*

Similar phenomena take place with other substances: for instance, solid cast-iron will float when put into molten cast-iron at a comparatively low temperature; but if the molten cast-iron is at a white heat, the solid iron will sink.

At the British standard temperature of 62° Fahr. we have—

1 gallon of pure fresh water			=	10 lbs.
224	„	„	„ =	1 ton.
6·23	„	„	„ =	1 cubic foot.
35·9 cubic feet	„		„ =	1 ton.

To revert to the thermometer as a means of detecting the presence of ice by a fall in the temperature of the sea surface. In a letter to the author, Lord Kelvin says:—

"The conducting power of water is so small, that there would be absolutely no cooling effect by conduction to a distance from an iceberg; but there might be a considerable effect by the cold and light fresh water running down from the iceberg, and spreading far and wide over the surface of the sea." **Lord Kelvin on conducting power of water.**

This seems a reasonable supposition, but it is more than likely that the film of cold fresh water would be broken up by the agitation of the wind and waves, and, in any case, disturbed and turned over by the plough-like action of a vessel's bow going at speed. Under these circumstances the hydrometer would be no better than the thermometer. **The Hydrometer.**

Again, it is well known that, about the Banks, the Labrador Current is *sometimes* colder when no ice is to be seen than it is when the contrary is the case. In winter its surface temperature even falls to 28° Fahr. Large icebergs have been actually passed at a distance of a quarter of a mile, and the sea surface temperature carefully tested, without finding a single degree of difference from what previously existed when there were none in sight.†

* Sea water differs from fresh water in that it continues to increase in density as the temperature is lowered, till freezing takes place.

† A reference to the Pilot Charts issued monthly to navigators by the Meteorological Office, London, and by the United States Hydrographic Office, shows that in September, 1893, a remnant of a berg was passed in 36° N., 30° W., and fifteen days later a similar piece of ice was sighted in 37° N., 18° W.; while, in July, 1890, a portion of a berg was reported in 49° N., 24° W. In September, 1906, the steamship *Lord Lansdowne* passed within 20 yards of a small block of ice, in 54° N., 22° W. In September, 1895, two pieces of ice, 30 feet high and 300 feet to 400 feet long, were passed in 36° 35′ N., 71° 36′ W. Turning to the Southern Ocean, ice was sighted in April, 1894, by a vessel in 26° 30′ S., 25° 40′ W.; and in August, 1895, seven bergs, of from 70 feet to 200 feet in height, were passed only 55 miles south-east of Cape Agulhas.

It may be fairly assumed, therefore, that no reliance is to be placed upon the thermometer as an immediate or direct means of detecting the presence of any kinds of ice, whether the amount be much or little. In fog it will simply tell you when the ship has entered the cool current, which may, or may not, be ice-bearing.

In time of danger it is unwise to neglect *any* precaution, therefore by all means continue to use the thermometer. But let not so doing lull one into a false sense of security, which might terminate in a rude awakening; much better to go quite slow when in the ice latitudes, now so well mapped out on the Admiralty charts; keep a hand aloft, and on the forecastle; stop the ship occasionally, and listen for the sound of breakers, or the echo of the steam whistle. If it were only more practicable, a gun would be very useful, as giving a better echo.* A large iceberg will denote its presence, even on the darkest night, by a sort of whiteness or halo, known as "ice blink." This expression has the same significance, in its own line, that "loom" has in relation to the land.

"Ice Blink."

Look out for, and take heed of, any sudden change in the *air* temperature—perhaps of 10° or 12°—more especially when the temperature is already low. Detached pieces of ice, which are often to be met with in the vicinity of field-ice or bergs, are a good indication. These loose pieces drift more rapidly than the large masses, and on this account, when navigating among ice, always endeavour to pass on the weather side of ice islands or bergs. From the position of their centre of gravity being altered by the thawing process, these enormous masses of congealed water sometimes lose their balance, take a sally, and topple over on their broadside. At others, huge fragments break off and fall into the sea with a great commotion. By the whalers this is termed "calving."

"Calving."

Northern bergs are smaller, and less tabular, than those of the South. The former are shed by Arctic glaciers; the latter may be broken off the Antarctic ice-cap by seismic disturbances. In 1854, a hook-shaped berg endangered ships in the South Atlantic some months. The longer shank stretched 60 miles; the shorter, 40 miles. Between was a *cul-de-sac*, 40 miles wide

Heights of Bergs.

Bergs over 500 feet high are rare in the North Atlantic; but many over 700 feet high visit the Southern Ocean, as indicated in the following table.

* It is but right to state that fog itself often gives a faint echo, which might be very misleading; and Professor Tyndall, in the experiments already alluded to, found aerial echoes of great intensity and long duration proceeding from air of most perfect optical clearness; so that an echo may have an entirely different origin to what is supposed.

Ocean. Period.	Year.	Month.	Lat.	Long.	Estimated Height in Feet.	Estimated Length in Miles.	Ship Reporting.
North Atlantic. 1890–1915. Bergs estimated to be 600 ft., or above, reported during the 26 years ended 1915.			°	°			
	1890	January	45 N.	49 W.	700	—	Mineola
	1892	May	46 ,,	47 ,,	600	—	Hafiz
	1896	,,	43 ,,	49 ,,	600	—	Maryland
	1899	April	43 ,,	44 ,,	600	—	St. Andrew
	1903	March	46 ,,	49 ,,	600	—	Energia
	1906	May	48 ,,	45 ,,	1,000	—	Marie
	,,	June	42 ,,	49 ,,	700	—	Paola Madre
	,,	July	52 ,,	51 ,,	600	—	Puritan
	,,	,,	52 ,,	54 ,,	700	—	Norden
	1915	,,	47 ,,	47 ,,	800	—	Principelle
Southern Ocean. Bergs estimated to be 800 ft., or above, in height, reported during the 32 years ended 1915.	1884	June	44 S.	49 E.	1,700	—	Emil Julius
	1887	September	58 ,,	66 W.	900	—	Richard Wagner
	1890	October	50 ,,	118 ,,	1,000	—	Noel
	1891	February	53 ,,	141 ,,	1,000	10	Marianna
	1892	April	46 ,,	36 ,,	1,000	—	Cromdale
	,,	May	44 ,,	30 ,,	1,000	40	Strathdon
	,,	June	45 ,,	37 ,,	900	—	County of Edinburgh
	,,	October	55 ,,	94 ,,	800	½	Liverpool
	1893	January	50 ,,	45 ,,	1,500	3	Loch Torridon
	,,	February	50 ,,	47 ,,	1,000	—	Cutty Sark
	,,	March	50 ,,	45 ,,	1,200	—	Turakina
	,,	,,	50 ,,	47 ,,	980	—	Atalanta
	,,	,,	51 ,,	49 ,,	800	—	Marion Inglis
	,,	April	49 ,,	51 ,,	1,000	2	Brier Holme
	,,	May	50 ,,	52 ,,	1,000	—	Charles Racine
	,,	September	43 ,,	5 ,,	1,000	—	Loch Eck
	,,	,,	50 ,,	51 ,,	980	5	Woosung
	,,	November	43 ,,	42 ,,	900	4	Pisagua
	1894	January	47 ,,	45 E.	890	—	Barmen
	,,	,,	45 ,,	30 ,,	800	1	Lodore
	,,	November	44 ,,	9 ,,	830	—	Rigel
	1895	December	46 ,,	29 ,,	900	—	Culgoa
	,,	,,	46 ,,	30 ,,	900	—	Loch Bredan
	1896	,,	45 ,,	50 ,,	1,500	1	Charles Racine
	,,	,,	47 ,,	60 ,,	820	—	Port Melbourne
	1897	January	45 ,,	42 ,,	800	—	Ellora
	,,	,,	45 ,,	60 ,,	800	¼	Nineveh
	,,	February	45 ,,	83 ,,	800	—	Gulf of Bothnia
	1901	September	50 ,,	130 W.	1,000	—	Loch Katrine
	1902	,,	56 ,,	67 ,,	1,000	½	Sokoto
	,,	October	44 ,,	31 ,,	1,000	—	Curzon
	1904	November	52 ,,	44 ,,	1,500	7	Zinita
	1906	May	57 ,,	64 ,,	1,000	—	Belen
	,,	June	58 ,,	70 ,,	800	1	Poltalloch
	,,	July	56 ,,	67 ,,	1,000	1	Bossuet
	,,	,,	56 ,,	62 ,,	800	3	Palgrave
	,,	October	51 ,,	56 ,,	800	—	Smeroe
	1908	August	49 ,,	42 ,,	1,300	10	Cognati
	1909	December	50 ,,	47 ,,	1,000	—	Walden Abbey
	1910	January	50 ,,	47 ,,	980	—	Eugene Pergeline
	,,	February	57 ,,	133 ,,	1,000	—	Invertay
	,,	August	52 ,,	57 ,,	1,000	—	Halewood
	1911	May	51 ,,	131 ,,	1,000	—	Wynford
	1912	May	52 ,,	50 ,,	800	1	Hafrsfjord
	,,	August	50 ,,	63 ,,	1,090	5	Metropolis
Southern Ocean Selection Prior to 1860.	1738	December	52 S.	10 W.	1,200	—	L'Aigle la Marie
	1833	January	55 ,,	149 ,,	840	—	Arethusa
	1840	August	38 ,,	15 E.	1,000	—	Gen. Baron v. Geen
	1853	March	53 ,,	15 ,,	960	—	Agneta
	,,	October	56 ,,	119 W.	900	—	Tudor

Having treated in the preceding pages on the relative densities of sea and fresh water, it may not be out of place to introduce the rule for determining how much a ship will lift in sea water that has been loaded in fresh. As masters and owners know to their cost, the Board of Trade people give an eye—and very properly so—to the possibility of overloading, and this matter of the different powers of flotation of fresh and salt water is sometimes made to do duty as a stalking-horse by the innocent and simple-minded transgressor, who, of course, is much to be pitied when the inexorable law mulcts him, say in £100 and costs.

Here is the rule which will enable the master to keep his money in the Savings Bank :—

Immersion of ships in fresh and salt water. The mean specific gravity of sea water at the standard temperature of 62° Fahr. is assumed to be 1·026, and on this the following very simple calculation is based. The master is, of course, provided with a *Displacement Scale* of his vessel.

Multiply the displacement corresponding to the draught by ·026; the answer will be in *tons;* divide by the number of tons per inch of immersion at this draught, taken from the Displacement Scale ; the answer will be in *inches.*

Example :—A ship when loaded to a mean draught of 20 feet has in salt water a displacement of 2,643 tons; her displacement at this draught is 13·6 tons per inch. Required to know what difference of draught there will be between river and sea water.

2,643 tons × ·026 = 68·7 tons.
68·7 „ ÷ 13·6 = 5 inches.

For all practical purposes it may be taken that a vessel proceeding from river water into sea water rises ¼-inch for each foot of her mean draught, thus :—

20 feet at ¼-inch per foot = 5 inches.

PART II.

CHAPTER I.

INTRODUCTORY.

THIS portion of the book is almost entirely devoted to the methods of finding a ship's position at sea, which, in the opinion of the author, present the readiest and most perfect means of attaining this end.

Observations of the Moon

Those founded on observations of the Moon are purposely omitted as not coming under this heading. They require so many petty and vexatious corrections, which spin the calculations out to a weary length, that they are abandoned as practically useless. Nor need this be regretted, if the navigator will only learn to make use of the many and peculiar advantages offered by the dozens of stars which are hour by hour at his disposal on any fine night.

Prevailing idea about Star observations.

There is, unfortunately, among sailors a very general and most erroneous notion that stellar observations and their calculation are something much too high and mighty to be tackled by ordinary mortals, and that at least a "University education" is required to cope with them. This is a very mistaken idea, which should be well secured to the grindstone, or a furnace bar, and thrown overboard in deep water, never more to come to the surface. Stellar observations are, in reality, no more difficult or complicated than the every-day methods of calculation by the sun. Anyone with fair sight is equal to the actual "taking" of the star, which merely requires a little practice; and "the working out" is *quite as short*, and readily learned.

"Wrinkles" has already done much to popularise star observations, and this edition hopes to do very much more by the introduction of a special Star Chapter and special Star Tables.

Best time for observing.

The most favourable time for observing is undoubtedly during morning and evening twilight, when the horizon is at its best. A man, however, of ordinary vision, and using *a good star telescope* and *well silvered sextant glasses*, will find little difficulty at any time on a *clear* night—especially if the moon be up—in obtaining all he may want in the way of reliable sights.*

Star telescope for sextant.

Star telescopes are now made in great perfection, and 'best' sextants are often fitted with most charming little binoculars in aluminium. It goes without saying that these must be *really well made and fitted*, and that the collimation adjustment must be perfect (*see* Appendix C). From this it follows that you must not expect to get them altogether for an old song.

Youngsters frequently display considerable aptitude in becoming acquainted with the stars and planets. This should always be encouraged, and once fairly entered on the subject, they will find the study of the heavens a most absorbing as well as profitable occupation during the long hours of the night watches.

Constellations.

In learning to recognise these bodies, it is just as well to throw on one side as useless—indeed, as misleading—the absurdly grotesque figures of the constellations given to them by the ancients. It is much better to engraft them on the memory by aid of the less fanciful ones, such as squares, triangles, &c., which form leading marks to the principal navigational stars, of which there are some fifty or thereabouts.

There is no part of our entire subject which the author is more anxious to press upon the attention of the navigator than this matter of star observation.

Chowder-headedness.

No reason exists why every man in command should not be thoroughly proficient. "Star chasing" is within the reach of all who choose to try. There are, however, men afloat who will not try, and who, for downright, double-barrelled, copper-bottomed, bevel-edged bigotry, are matchless in all other professions. For such as these this book is not written, as they are hopeless cases, whose pig-headed obstinacy is only equalled by their ignorance. Happily the class will soon become extinct.

It is a true saying that "there is no royal road to learning." Everything requires more or less trouble in the attainment. Even so long ago as 1607, John Davis—an Elizabethan navigator

* In connection with this subject, it is interesting to know that, with the aid of a small astronomical telescope, stars *even of the lesser magnitudes* are distinctly visible throughout the entire day; but those in the neighbourhood of the sun can only be discerned by the more powerful instruments of observatories.

of "North-West Passage" fame—has it in his *Seaman's Secrets:* "It is not possible that any man can be a good and sufficient Pilot or skilful Seaman but by painful and diligent practice." However, for the encouragement of those not yet posted in navigation by the stars, the writer can promise that, when once they have taken up the subject with a fixed determination to master it, they will be agreeably astonished at how rapidly the dreaded difficulties will disappear, and their labours be rewarded by the feeling of comfort, and saving of anxiety at critical times, afforded by the certain knowledge of their ship's whereabouts.

Comfort derived from being familiar with star problems.

This second part of the book is essentially one of figures, and it is desirable at the commencement to dwell upon certain important points in connection with their application.

To begin with, there are some Navigators who every day, in ordinary course, use Tables of Logarithms, and yet have no idea how they are formed. Nor are they aware of the simple fact that from Log. Sines and Log. Tangents it is easy to find the Logarithms of the other Trigonometrical functions, thus:—

Log.

$$\text{Sin.} = \text{tan} \times \text{cos.} = 1 \div \text{cosec} \quad \therefore \text{L. sin.} = \text{L. tan.} + \text{L. cos.} = 0 - \text{L. cosec.}$$
$$\text{Cos.} = \text{cot.} \times \text{sin.} = 1 \div \text{sec.} \quad \therefore \text{L. cos.} = \text{L. cot.} + \text{L. sin.} = 0 - \text{L. sec.}$$
$$\text{Sec.} = \text{tan.} \times \text{cosec.} = 1 \div \text{cos.} \quad \therefore \text{L. sec.} = \text{L. tan.} + \text{L. cosec.} = 0 - \text{L. cos.}$$
$$\text{Cosec.} = \text{cot.} \times \text{sec.} = 1 \div \text{sin.} \quad \therefore \text{L. cosec.} = \text{L. cot.} + \text{L. sec.} = 0 - \text{L. sin.}$$
$$\begin{array}{ll} \text{Tan} = \text{sin.} \times \text{sec.} = 1 \div \text{cot.} & \therefore \left.\begin{array}{l}\text{L. tan.} = \text{L. sin.} + \text{L. sec.} \\ \qquad\quad = \text{L. sin.} - \text{L. cos.}\end{array}\right\} = 0 - \text{L. cot.} \\ \quad = \text{sin.} \div \text{cos.} & \end{array}$$
$$\begin{array}{ll} \text{Cot.} = \text{cos.} \times \text{cosec.} = 1 \div \text{tan.} & \therefore \left.\begin{array}{l}\text{L. cot.} = \text{L. cos.} + \text{L. cosec.} \\ \qquad\quad = \text{L. cos.} - \text{L. sin.}\end{array}\right\} = 0 - \text{L. tan.} \\ \quad = \text{cos.} \div \text{sin} & \end{array}$$

These are professional items that *ought* to be known if the tyro has but a shred of ambition.

Again, it is worth while knowing that when computing an angle, four figures in the logs. will give it to the nearest *minute* of arc; five figures will ensure accuracy to about 5″, and six figures to 0″·5. Though Tables of logs. to seven places of decimals and upwards are published, they are not required in Practical Navigation. They give results to 0″·05 and under.

The writer has frequently seen young officers laboriously working out their sights, schoolroom fashion, to the nearest second of arc, and flattering themselves that because they had done so, the *result* must be equally accurate. In effect they build up elaborate and imposing processes of calculation on what may be—and too often is—an imperfect foundation, thus leading to dangerous self-deception.

Needlessly working to seconds.

This attempt at exactitude, however praiseworthy in other respects, would ofttimes shew an ignorance of governing principles which it is one of the objects of this book to seek to remove.

As that master of common-sense reasoning, Professor Huxley, neatly puts it, "Grinding peascods in a mill of super-excellent grinding qualities will not give us wheaten flour."

Raper's remarks regarding precision in working.

Raper also, in the preface to his unsurpassed work on Navigation, says:—"Very indistinct and erroneous notions prevail among practical persons on the subject of accuracy of computation; and much time is, in consequence, often lost in computing to a degree of precision wholly inconsistent with that of the elements themselves. The mere habit of working invariably to a useless precision, while it can never advance the computer's knowledge of the subject, has the unfavourable tendency of deceiving those who are not aware of the true nature of such questions, into the persuasion that a result is always as correct as the computer chooses to make it; and thus leads them to place the same confidence in all observations, provided only they are *worked* to the same degree of accuracy."

This idea is unhappily not confined to the youngsters of the profession; it has taken root in some of the older members as well, and it is therefore incumbent to write strongly against a fallacy which is dangerous in its tendency, and must frequently have contributed to fatal disaster.

Uncertainty in much of the data employed in computing.

In all observations errors must be made: the best instruments have imperfections; and no man, however equable his temperament, can always rely on making a proper use of his senses.

It has been shewn, in previous pages, that there is often much doubt at sea as to the true place of the visible horizon, so that the altitude is never free from suspicion of inaccuracy. In addition to this, other data, peculiar to the problem, may be more or less unreliable; for example, the latitude is often uncertain to three or four miles. In working out the time at ship, an error to this amount would, under some circumstances, falsify the longitude to a serious degree, whilst in other cases a similar error in the same problem would have no appreciable effect.

Again, we have instrumental defects depending not only upon errors in workmanship, but upon such as arise from temporary derangement due to a variety of causes.*

* With regard to these latter, it is the peculiarity of astronomical observations to be the ultimate means of dragging to light all defects of workmanship and adjustment in instruments, which by their minuteness elude every other mode of detection.

It is therefore necessary, not only to exercise judgment as to the degree of close-working any given observation will admit of, and may require, but to endeavour so to select or combine problems and methods, that the errors, of whatever nature they may be, will either neutralize each other in the final result, or so unmistakably declare themselves as to be capable of easy elimination. The precise way in which this is done will be described under each different observation. **Working to seconds.**

The sixth chapter of Raper's Introduction, wherein he treats of "limit of error" and "degree of dependence," should be carefully noted in connection with this most important subject.

Whilst the folly of working to seconds in the majority of cases is thus put before the reader, and the striving after an impossible, though pretentious, perfection in so doing, is shewn to be a snare and a delusion, it is by no means to be understood that loose working, or a careless and hasty manner, either of observing or computing, should in any way be practised or tolerated. On the contrary, anything which can *really* increase the accuracy of the observations, or the correctness of the position deduced from them, must be diligently sought for and applied.

"Rules of Thumb," when founded upon correct reasoning, are invaluable; but, on the contrary, "Rules of Thumb" *not* founded upon correct reasoning are a positive bane to the practical man, for whose benefit they are generally intended. Seeing that the safety of life and property depends upon the soundness of his judgment at critical times, the Navigator, of all men, should cultivate his reasoning powers to the fullest extent.

To place faith in rules learnt Poll-parrot fashion, and to navigate a ship thereby, is indeed to tempt Providence. *It is a miserable and discreditable system which permits it.*

The writer has no sympathy with mechanical processes which are simply committed to memory, any more than he has with the bygone method of teaching geometry, wherein the student was allowed to memorize the demonstration. In each problem which engages his attention, the Navigator, to be a Navigator, should have the *principle* at his finger-ends; so that, relying upon the accuracy of his reasoning rather than on the distinctness of his recollection, he may be able to solve it whenever called upon. **Nautical Kinder-Garten required.**

It is the possession of the requisite mental activity, or "capacity for taking trouble," and the power of selecting the most advantageous means out of the many at his disposal, which constitute the real test of a man's ability as a Navigator, and shew that his knowledge is not superficial, but based on strictly sound principles, which cannot mislead. If he intends to make his mark in the profession *he must work*, and in all things take as his motto, "The best that I *can* do, is the poorest that I *will* do." Even if not specially gifted, either with intellect or education, he need not despair if otherwise made of the right 'grit.' The race is not always to the swift, as exemplified in the fable of the Hare and the Tortoise. It is wonderful what dogged perseverance will accomplish. The career of the writer of these pages is a case in point.

Work, the stepping-stone to success.

As a suitable finish to these remarks, it will probably not come amiss to explain what is meant by Parallax (astronomically considered), and why, in practical Navigation, it is unnecessary to take it into account except in rare instances.

Diurnal Lunar Parallax.

Let us then imagine an inhabitant of the Moon to be regarding our Earth, which, for the time being, we will suppose to be truly circular, and that a tiny speck indicated to him the exact centre of its disc. If, now, he were to measure with a sextant the angle between this tiny speck and the Earth's limb, or in other words, the Earth's semidiameter, he would obtain a *mean* result of 57′ 3″: or what is the same thing, a base line of 3963 miles would, at the Moon's mean distance from the Earth, subtend an angle of nearly 1°; a simple problem in right-angled trigonometry which any one is equal to.

Diurnal Solar Parallax.

Next let us imagine our friend with the sextant to have shifted his observatory to the Sun, and from that far-off luminary to have repeated his measure of the Earth's semidiameter: this time, owing to the greatly increased distance, he would get rather less than 9″ as its mean value, and these two angular quantities would respectively be termed the Moon's and Sun's *Geocentric Horizontal Parallax.*

Annual Stellar Parallax.

If, proceeding yet further, he winged his way to the *nearest* of the fixed stars—and, travelling as fast as light does, it would take him about four years to get there—our celestial traveller, on looking back for this world, which *we* think so immense, would find that it had disappeared by very reason of its insignificance.* But supposing it still discernible, and that it could be watched whilst moving in its orbit round the sun, he would then be able to get the angle subtended by a straight line connecting the centres of the two bodies. This straight line, if measured when

* The velocity of light is 186,320 miles per second, and the constant of aberration is 20″·47. The earth's mean motion in its orbit is 18½ miles per second.

the Earth had reached its extreme point of travel to the right and again to the left of the Sun, and the mean taken, would give the observer the very respectable base of close upon 93 millions of miles. But notwithstanding the enormous length of such a base, the angle it would subtend at the place of the *nearest* fixed star would actually be less than 1″ of arc, and would be spoken of as the Star's *Annual* or *Heliocentric Parallax.*

Distance of nearest star

This will convey some faint idea of how far away in space that nearest star must be; expressed in words, it is about twenty-five billions of miles, whilst

25,000,000,000,000 miles

represent it in figures. In the contemplation of even these numbers the imagination is lost; how then if we seek to gauge the more profound depths of the universe?

The foregoing explains what is meant when allusion is made to the Moon's Parallax, the Sun's Parallax, and Stellar Parallax; but to determine the two latter is no easy job, nevertheless it must be done if we wish to know our distance from these bodies.

Mars and Venus.

An accurate determination of the distance of the sun from this earth is one of the vexed questions of Astronomy. Many very costly attempts have been made to solve it—notably by well equipped expeditions organised by this and other countries to observe the periodically recurring Transits of Venus, commencing with that of 1761; also by David Gill's memorable observations of Mars in opposition made at the Island of Ascension in 1877.* But, notwithstanding the wonders which science can accomplish, despite the intellectual resources of our ablest men, the sun's distance remains uncertain to the extent of at least a third of a million of miles, plus or minus. Nor need this be considered a reproach when the extreme delicacy of the problem is understood. It may in some sort be imagined from the fact that *one-tenth* of a second (0″·1) of Solar Parallax represents in round numbers a *million* of miles.

Solar Parallax methods.

As the world progresses, other and more reliable methods will be invoked to set at rest this most interesting, important, and difficult question. To this end the Planetoids or Minor Planets are certain to be systematically observed; one of their many advantages being the comparative frequency with which they lend themselves for the purpose. It is believed that an exten-

* For a popular account of "How it was done," the reader is referred to "Six Months in Ascension, by Mrs. Gill—An Unscientific Account of a Scientific Expedition."—London: John Murray.

sive series of such observations, combined with, perhaps, increased instrumental perfection, will—even before the end of the present century—shed sufficient light on the subject to place not only the first, but the second, decimal figure beyond the realms of controversy, and this is saying a good deal.

Meanwhile ordinary folks—with no special hankering after this kind of knowledge, and to whom a little is very satisfying—may well be content to accept 8″·8 as the sun's Mean Equatorial Horizontal Parallax. These are nice easy figures to remember, and are generally regarded as not very wide of the truth: they correspond to a distance of nearly 92,900,000 of *statute* miles. It takes light 8^m $18\frac{1}{2}^s$ to traverse this space, and to count 93 millions would require an unbroken period of nine months!!

Parallax as affecting navigation.

We will now return to mother Earth, to see in what way Parallax affects Navigation.

In the theory of Nautical Astronomy—for certain mathematical reasons—all observations of the heavenly bodies are supposed to be made at the centre of our globe, but as this is clearly impracticable (except to such as the late Jules Verne) an allowance has to be made which goes by the general name of *Parallax* In this connection, therefore, Parallax is the angular difference between the *Apparent* place of a heavenly body as seen by an observer from any station on the Earth's *surface*, and its *True* position as supposed to be seen from the Earth's *centre.*

Sensible and Rational Horizons.

With us angular altitudes of the heavenly bodies are of necessity measured from the *Sensible Horizon,* which is a plane passing through the eye of the observer at right angles to a freely suspended plumb-line, whereas they ought to be measured from the *Rational Horizon,* which is parallel to the other, but passes through the Earth's centre.*

Now it has been shewn that the distance of the fixed stars is so vast, that to them our Sensible and Rational Horizons—though nearly 4,000 miles apart—are virtually one and the same thing, so that whether a stellar observation is made at the centre or surface of the Earth matters not; the altitude in either event is exactly the same.

* Remember that the Sensible and Visible horizons are not identical. The visible horizon is the line where sky and earth meet. On land it is an irregular line broken by hills, trees, &c., and of no astronomical value. But at sea it is a true circle, though not a "Great Circle," and of immense importance to the navigator. The visible horizon is depressed below the sensible horizon by an angular amount depending upon the observer's elevation above the water. This angular amount is termed *Dip of the Horizon.* The formula for True Dip is given in Appendix (N).

In the case of the Sun it has also been shewn that the *greatest* effect would be less than 9″, a quantity so small that in ship work it is not worth notice; and the same may be said of the Planets. But where our next-door neighbour the Moon is concerned, Parallax is an important element, and cannot be disregarded. Therefore, if altitudes of the Moon could be taken simultaneously from the surface of the Earth and from its centre, they would be found to differ considerably, the altitude observed at the Earth's centre being the *true* one, and the greater of the two. The correction for Parallax, therefore, is always additive.

If the observation were made at the Earth's centre just when the Moon happened to be in the Sensible Horizon of a spectator at the surface, this difference—amounting to nearly 1°—would then be termed the Moon's *Horizontal* Parallax, and would be equivalent to the Earth's semidiameter as measured with his sextant by the "Man in the Moon."

As the altitude of a heavenly body increases, the correction for Parallax decreases, until it absolutely vanishes when the body reaches the zenith.

Parallax in altitude.

Except when the body is in the horizon, this correction is spoken of as "Parallax in altitude."

From the foregoing we deduce the practical results that in observations of the stars Parallax is totally insensible, and that in observations of the Sun or Planets it is so small that it may be "left out in the cold" without detriment to Navigation. The Moon, then, is the only body which is seriously affected by it, and as for this and other reasons we decided long ago to send the Moon to Coventry (except when required for Azimuths), Parallax may pack up and go with her.

Movement of the Solar System in space.

Rest in Nature seems to be impossible. We on earth know, by astronomical every-day teaching, that our globe and the other planets continually circle round the Sun as the centre of this particular system; yet it is seldom brought home to our minds that the Sun himself, with all his 'following,' is speeding through space just as the other 'Fixed (?) Stars' are doing—some at the enormous rate of 100 miles a second.

The solar apex.

The question of the exact position of the point in the Heavens towards which the Sun with his system is travelling, has been the subject of much research and computation. The present co-ordinates are now considered as being about R.A. 267°, and Declin. + 31°, giving a position near the eastern edge of the constellation Hercules. The bodily rate of translation of the entire system is computed to be between 15 and 20 miles per second.

CHAPTER II.

SKY PILOTAGE.

"The stars are truly the sailor's safeguards."

There seems no end to the star books—large and small—illustrated by maps of sorts, in which the easy-going mariner may invest his loose coin; and the cry is "still they come." He might *buy* but he could never *read* the half of them: like shelling shrimps, life would hardly be long enough for such an undertaking. It is a pity that in many instances these celestial guides altogether spoil themselves by over-doing it. Why they should not, if intended for navigational purposes, rest content with navigational stars—leaving those of lesser magnitudes to be peered at and pondered over by shore-going amateurs—no man can understand; except, perhaps, that in the opinion of their authors, size confers respectability: thus, unnecessary matter is inserted, presumably by way of padding. The book-making result is so formidable, both in appearance and price, that many men are 'choked off' from taking up the subject, and the book defeats its own object.

Book-making.

A few might indeed be named which are excellent in their way, and fairly free from this defect. Nevertheless it is quite certain that the navigator of average intelligence can, if he chooses, learn all that is requisite without the questionable assistance of intricate Atlases and special books. There is no mystery and very little difficulty about the matter: a chapter of "Wrinkles"—albeit a long one—combined with a little star-gazing in the night watches, will fully meet the case and save his dollars.

Star lore easily acquired.

Sir J. Herschel has aptly remarked that, "Every well determined star, from the moment its place is registered, becomes to the astronomer, the geographer, the navigator, the surveyor, a point of departure which can never deceive or fail him, the same for ever and in all places, of a delicacy so extreme as to be a test for every instrument yet invented by man, yet equally adapted for the most ordinary purposes; as available for regulating a town clock as for conducting a navy to the Indies, as effective for mapping down the intricacies of a petty barony as for adjusting the boundaries of Trans-Atlantic empires."

Epitome Table of Mean places

Most epitomes have a list of the *Mean* places of the principal stars for some specified year (generally of a past decade), with the annual variation of Right Ascension and Declination, by which to reduce from the given (antiquated) epoch to any other; but it may be said at once that this time-honoured table is seldom or never used. Why its insertion is continued in the revised editions, except on the principle of 'Follow my leader,' is hard to imagine.

Apparent places really required.

In calculations for ship's position, it is infinitely better to take out the elements from the *Naut. Alm.* for the current year. As the *Apparent* places of the stars are given for every tenth day, there is no need to make any reduction whatever, and the labour of doing so—with possibility of mistake—is saved.

In the *Naut. Alm.* for 1895 the requisite data were given between pages 316–371. The hours and minutes of Right Ascension, and the degrees and minutes of Declination, are placed as constants at the head of their respective columns, and belong equally to all the numbers below them. This arrangement has made it necessary in numerous instances to continue the seconds beyond 60, as the width of the page would not permit of otherwise indicating any change in the minutes. Thus the apparent declination of *Aldebaran*, at page 325 on October 18th, 1895, is registered at 16° 17′ 71″·1, and is to be read as 16° 18′ 11″·1 N.*

Number of navigational stars.

Now, in view of the fact, patent to anyone who chooses to look, that there are about 100 *Naut. Alm.* stars of the 1st, 2nd, and 3rd mags., it is obvious that it can seldom or never be worth while bothering with the lesser lights of the star books. Except under specially favourable circumstances, even 3rd mag. stars are

The *Naut. Alm.* is now published in two parts. Part I., price a shilling, is more particularly for the use of seamen. This reform was much needed, but the writer does not altogether agree with the omission of the Table of Apparent Places of the Stars, nor with the observation in the second para. of the Preface, that "the Mean Places are sufficiently correct for the purposes of navigation by the Sea Horizon." Also, the authorities seem to have forgotten that those navigators who rate their chronometers on shore by stars and artificial horizon, will have to hamper themselves with Part II. if they aim at the accuracy which is so desirable. The Apparent Places should certainly be included in Part I.

CHAPTER II.

SKY PILOTAGE.

"The stars are truly the sailor's safeguards."

There seems no end to the star books—large and small—illustrated by maps of sorts, in which the easy-going mariner may invest his loose coin; and the cry is "still they come." He might *buy* but he could never *read* the half of them: like shelling shrimps, life would hardly be long enough for such an undertaking. It is a pity that in many instances these celestial guides altogether spoil themselves by over-doing it. Why they should not, if intended for navigational purposes, rest content with navigational stars—leaving those of lesser magnitudes to be peered at and pondered over by shore-going amateurs—no man can understand; except, perhaps, that in the opinion of their authors, size confers respectability: thus, unnecessary matter is inserted, presumably by way of padding. The book-making result is so formidable, both in appearance and price, that many men are 'choked off' from taking up the subject, and the book defeats its own object.

Book-making.

A few might indeed be named which are excellent in their way, and fairly free from this defect. Nevertheless it is quite certain that the navigator of average intelligence can, if he chooses, learn all that is requisite without the questionable assistance of intricate Atlases and special books. There is no mystery and very little difficulty about the matter: a chapter of "Wrinkles"—albeit a long one—combined with a littl[illegible] gazing in the night watches, will fully meet the case [illegible] his dollars.

Star lore easily acquired.

Sir J. Herschel has aptly remarked that, "Ev[illegible] mined star, from the moment its place is reg[illegible] the astronomer, the geographer, the navi[illegible] point of departure which can ne[illegible]

for ever and in all places [illegible]
for every instrument yet invented [illegible]
for the most ordinary purposes [illegible]
town clock as for conducting a [illegible]
for mapping down the intricacies of a [illegible]
ing the boundaries of Trans-Atlantic [illegible]

Most epitomes have a list of the [illegible]
stars for some specified year [illegible]
the annual variation of Right Ascension [illegible]
which to reduce from the given [illegible]
but it may be said at once that [illegible]
or never used. Why its insertion [illegible]
editions, except on the principle of [illegible]
imagine.

In calculations for ship's position [illegible]
out the elements from the *Naut.* [illegible]
the *Apparent* places of the stars [illegible]
there is no need to make any [illegible]
of doing so—with possibility of [illegible]

In the *Naut. Alm.* for [illegible]
between pages 316–371. The [illegible]
sion, and the degrees and [illegible]
constants at the head of [illegible]
equally to all the numbers below [illegible]
made it necessary in numerous [illegible]
beyond 60, as the width of [illegible]
wise indicating any change in [illegible]
declination of *Aldebaran* at page [illegible]
registered at 16° 17′ 71″·1, [illegible]

Now, in view of the [illegible]
look, that there are about [illegible]
and 3rd mags., it is [illegible]
while bothering with [illegible]
under specially [illegible]

The *Naut. Alm.* [illegible] ...ne lifts
more particularly [illegible]
the writer does [illegible]
the Stars, nor [illegible]
Places are [illegible]
the authorities [illegible]
on shore by [illegible]
they aim [illegible]
include [illegible]

difficult of reflection in the mirrors of sextants that have "seen service."

A list of the more useful navigational stars, selected with special regard to their distribution in the heavens, will be found at the end of this chapter: being solely for general reference, it is unnecessary to do more than give the Right Ascensions to the nearest minute, and the Declinations to the tenth of a degree, In some instances, also, the very latest determinations of parallax are given; but where the one-hundredth of a second of arc means billions of miles, it is clear that our knowledge of star distances is of the rudest description.

Proper names.

Most of the listed stars have proper names, chiefly derived from the Arabic. The unchristened ones are distinguished by Greek letters prefixed to the constellation to which they belong. This is generally, but not always, done according to the star's 'order of merit;' for example, in the classification of the 'Twins,' *Castor* is marked α Geminorum, though not quite so bright as *Pollux*, which is marked β Geminorum. Long, long ago *Castor* was the brighter of the two, and the seniority then conferred upon it still remains. No doubt *Pollux* is jealous, but this very brotherly feeling need not vex the souls of mortals.

It is advisable, then, to be acquainted with the Greek Alphabet and here it is:—

Greek Alphabet.

α	Alpha	ι	Iota	ρ	Rho
β	Beta	κ	Kappa	σ	Sigma
γ	Gamma	λ	Lambda	τ	Tau
δ	Delta	μ	Mu	υ	Upsīlon
ϵ	Epsilon	ν	Nu	ϕ	Phi
ζ	Zeta	ξ	Xi	χ	Chi (Ki)
η	Eta	o	Omīcron	ψ	Psi
θ	Theta	π	Pi	ω	Omĕga

It is also just as well to have some little knowledge of such of the Constellations—if it were only their names—as figure in the list. Alphabetically they are as follows:—

ANDROMEDA.—A favourite subject with Royal Academicians. The painting represents a figure (in the costume of Eve before the Fall) chained to a rock, and in danger from a sea monster.

AQUILA.—The Eagle: associated with *Altair.*

ARGO NAVIS.—The ship Argo.

ARIES.—The Ram. One of the 'signs' of the Zodiac. It used to contain the 'first point of Aries,' but owing to the Precession of the Equinoxes, this imaginary point has now retrograded into the constellation Pisces, and will continue to retrograde until, in the course of nearly 26,000 years, it will have made the tour of all the signs of the Zodiac, and got back again to Aries, ready for a fresh start, and so on for ever and ever.

AURIGA.—The Charioteer. Contains conspicuous *Capella.*

BOÖTES.—The Herdsman. Identified with *Arcturus,* which outshines every other northern star.

CANIS MAJOR.—The Great Dog. Contains *Sirius,* the brightest star in the heavens.

CANIS MINOR.—The Little Dog. Noticeable for the very bright star *Procyon.*

CASSIOPEIA.—Associated with the chair of the lady bearing that name.

CENTAURUS.—The Centaur. Rides majestically through space in company with *Crux.*

CETUS.—The Whale. Contains *Mira,* the most wonderful of all the variable stars, but useless in navigation.

COLUMBA.—The Dove.

CORONA BOREALIS.—The Northern Crown. Not much of a 'show.'

CORVUS.—The Crow. Nautically, the 'Cutter's mainsail.'

CRUX.—The Southern Cross. Some thousands of years ago this Constellation was visible in England, but Precession—accountable for so many odd things—slowly but surely carried it South.

CYGNUS.—The Swan. Apparently so called because not in the least like one.

ERIDANUS.—The ancient name for the River Po.

GEMINI.—The Twins. Already referred to.

GRUS.—The Crane. The only weight this kind of Crane lifts is its food.

HYDRA.—The Sea Serpent.

LEO.—The Lion. Contains the 'Sickle.'

LIBRA.—The Balance.

LYRA.—The Lyre. Associated with *Vega.*

OPHIUCHUS.—The Serpent Bearer.

ORION.—A giant of that name who came to grief through falling in love. Not the first, nor yet the last.

PAVO.—The Peacock.

PEGASUS.—The Winged Horse.

PERSEUS.—Rescued Andromeda from the sea monster, and Andromeda very properly married him for so doing. This is as it was, is now, and ever will be.

PHŒNIX the fabulous.—Of no particular account as a constellation, and only distantly related to the Fire Insurance Co. of that name.

PISCIS AUSTRALIS.—The Southern Fish. Associated with *Fomalhaut.*

SCORPIO.—The Scorpion. Associated with the reddish *Antares.*

TAURUS.—The Bull. Contains the famous Pleiades, which, to unaided vision, consists of six or seven stars, but is, nevertheless, *known* to contain 2,326, *all duly counted.*

Miss Clerke's *History of Astronomy*, and *System of the Stars.*

In passing, it may be stated that Astronomers are indebted more to the photographic camera than to the telescope, as such, for probing the depths of space after this very searching fashion. This phase of celestial photography has been aptly termed the 'Astronomy of the invisible.' As Miss Agnes M. Clerke puts it, in her *History of Astronomy,* "The chemical plate has two advantages over the human retina. First, it is sensitive to rays which are utterly powerless to produce any *visual* effect; next, it can accumulate impressions almost indefinitely, while from the retina they fade after one-tenth of a second." And referring to this same subject in her *System of the Stars,* Miss Clerke says, "The unique power of the photographic plate as an engine of discovery, is derived from its unlimited faculty for amassing faint impressions of light. *By looking long enough* it can see anything there is to be seen." It is accordingly quite possible, by long exposure—say 3 or 4 hours—under favourable conditions, to photograph objects so faint as to be altogether beyond the optical power of *any* telescope to reveal.

TRIANGULUM AUSTRALIS.—The Southern Triangle.

URSA MAJOR.—The Great Bear.

URSA MINOR.—The Lesser Bear. Associated with *Polaris.*

VIRGO.—The Virgin. Contains the brilliant *Spica.*

To acquire a practical knowledge of the stars, either of two methods may be adopted; but as the one is largely mixed up with the other, both will be described. The first may be regarded more especially as the *Astronomical,* and the other as the *Astrographical* method. The latter mouthful, though not yet in the dictionary, will no doubt get there in time. We will give precedence to No. 1.

Co-ordinates.

When a sailor wishes to define his position, he resorts to *Latitude* and *Longitude;* the one giving a North and South, and the other an East and West direction. In like manner, to ascertain the whereabouts in the heavens of any particular body, he must turn up its *Declination* and *Right Ascension.*

Latitude and Declination.

Geographical Latitude and Declination correspond to each other. What Latitude is on the earth, Declination is on the sky. But between Right Ascension and Longitude there are points of difference, which, if passed over in silence, would lead to confusion.

Longitude and Right Ascension.

Geographical Longitude (which must not be confounded with Astronomical Longitude) is reckoned from a certain fixed terrestrial meridian, known as the *Prime Meridian,* and the nations of the earth are now pretty well agreed that the Royal Observatory of Greenwich is to be accepted as the *Universal* Prime Meridian. Longitude is measured both Eastward and Westward from Greenwich—180° in each direction; though it has been proposed that it should only be reckoned *Eastward* through the whole circumference of 360° of the earth's equator. It would certainly be a convenience if it were. Well, in similar manner the celestial equator is divided by Right Ascension, which, however, has as its zero or starting place, *not* the meridian of Greenwich, but the *Astronomical* Prime Meridian of the first point of Aries, indicated by the position of the sun at the vernal equinox.* Since "precession" causes this zero point to retreat slowly westward, it follows that the Right Ascensions of *nearly* all stars increase steadily year by year, apart from any movement "proper" to themselves. We see, therefore, that the *Astronomical* Prime Meridian is by no means a fixture like Greenwich.

Sidereal time and Right Ascension.

Although Right Ascension *may* be expressed in angular measure, it is much more common to express it in time, beginning with 0 hrs., and ending with 24 hrs., and *always* in the direction of from west to east. Sidereal noon at each spot on the earth is the moment when the first point of Aries crosses the meridian of *that spot.* The sidereal clock *at that spot* should then shew $0^{h}\ 0^{m}\ 0^{s}$, and its own particular sidereal day would forthwith commence. Now, in the northern hemisphere—looking south—the stars will pass in review from left to right. Seated thus at a transit instrument in England, when the sidereal clock of his Observatory shews $0^{h}\ 3^{m}$, the watcher of the heavens will find *Alpheratz* on the meridian, and $0^{h}\ 3^{m}$ is consequently its Right Ascension. Five minutes later, and lower down in the sky, will come *Algenib.* At 4 hrs. 30 m., *Aldebaran* will cross the

* Explained in the chapter on Time.

centre web in the graticule of the telescope at pretty nearly the same altitude as *Algenib*, and so on until the earth has made a complete revolution (one sidereal day), when the silent march past of the stars will be repeated at the same (*sidereal*) time as before. Therefore, to ascertain the R.A. of any star, the observer has merely to note the sidereal time of its passing his meridian.

Sidereal and Mean Solar day.

Now for another point of difference. The *sidereal day* is $3^m\ 55^s{\cdot}9$ shorter than the *mean solar day*, and, consequently, the first point of Aries (or any fixed star) will culminate that much earlier each succeeding day.* This is called its 'acceleration' on mean time. The beginning of the *sidereal day* does not, therefore, correspond to a definite fixed hour of *solar mean time*, but in the course of a year runs through *all* the hours of the ordinary day by which the affairs of life are regulated. To test this roughly, multiply 365 days by 4^m, and the result will be approximately 24 hrs. Hence, 366 sidereal days are equal to 365 mean solar days. For confirmation of this, look in the *Naut. Alm.* for March, and you will find that the sun's R.A. is $0^H\ 0^M\ 0^s$ when on the Equator. The "Sidereal Time," in the last column of Page II. for the month, would also be $0^H\ 0^M\ 0^s$ were it not given for *mean* time. Thence onward, month by month, it steadily increases, until in September, when the sun is again crossing the line, but this time in the opposite direction, the "Sidereal Time" has grown to 12 hrs., and continues to grow till it has attained the maximum of $24^H\ 0^M\ 0^s$ in the following March.

Seasonal visibility of stars.

The consequence is that those stars which are now rising in the east, at any given hour of *solar mean time*, will be found setting in the west at the same hour six months hence; whilst those which at any hour are now setting, will, at the same hour six months hence, be found rising. This, of course, applies to *any* part of the year, and six months before or after it.

Now, though roughly speaking the Right Ascensions of the stars do not vary in themselves, it has just been shewn that, owing to the stars coming so much earlier each evening, a given Right Ascension cannot be *directly* associated with any fixed hour of the day as indicated by a solar mean-time clock or chronometer; moreover, *sidereal* chronometers do not form part of a vessel's outfit; therefore, to utilise Right Ascension for star-finding, it becomes necessary to make a trifling calculation, which, in its simplest form, is as follows:—

* A sidereal clock, therefore, would not run with a mean time clock: supposing both to be started at the same instant, the sidereal clock would soon outstrip or lead the other. They would only agree *once* in the year.

Being at Greenwich, required to know at what hour (mean time) on April 15th, 1895, *Procyon* will be on the meridian.

	H. M.	
R.A. of *Procyon* = its sidereal time of meridian passage . .	7 34	Mean time of transit.
Sidereal time at Greenwich, *mean* noon (Naut. Alm., page 57) .	1 34	
Interval	6 00	

The above interval being expressed in *sidereal* hours, which are 10^s shorter than hours of mean time, there is 1^m to subtract. This is termed "retardation." *Procyon* will therefore transit at 5 hrs. 59 m. P.M. *mean* time.

Tables 27 and 27A of Raper give the approximate *apparent* times of the meridian passage of the principal stars, so that in sea practice the above operation—simple as it is—is reduced to one of mere inspection. If the thinking reader has carefully followed what has been put before him, he will scarcely require to be told how to find the *apparent* time of meridian passage independently of the Tables. Anyway here is the rule:—

From the star's R.A. (increased by 24 hrs. if necessary) subtract the R.A. of the sun at apparent noon (page I. of the month in the *Naut. Alm.*); from this subtract the "retardation," and the remainder is the apparent time required.

Taking the foregoing example, and still neglecting seconds, we have—

	H. M.	
R.A. of *Procyon*, April 15th, 1895 (N.A. page 332) . .	7 34	Apparent time of transit.
R.A. of the Sun, „ „ (N.A. page 56) . .	1 34	
Sidereal interval	6 00	
Retardation (Raper, Table 24)	− 1	
Apparent time of transit . . .	5 59 P.M.	

The reason why the result comes out the same as in the previous example is because on that day the Equation of Time is *nil*; or, in other words, mean and apparent times happen to be in agreement. This again amounts to saying that the *imaginary* mean sun is then exactly "in one" with the *visible* sun.

One more case with the observer still located at Greenwich ought to suffice.

What will be the *mean* time of *Procyon's* meridian passage on February 19th, 1895?

Transit at Greenwich.

	H.	M.
R.A. of *Procyon* = its sidereal time of merid. pass. + 24 hrs. =	31	34
Sidereal Time at Mean noon (N.A. page 21)	21	57
Sidereal interval	9	37
Retardation (Raper, Table 24)		− 1½
Mean time of transit at Greenwich .	9	35½ P.M.

To find the *apparent* time of meridian passage on same day:—

	H.	M.
R.A. of *Procyon*, Feb. 19th, 1895 (N.A. page 332) + 24 hrs. =	31	34
R.A. of Sun, „ „ (N.A. page 20) . . .	22	11
Sidereal interval	9	23
Retardation		− 1½
Apparent time of transit at Greenwich .	9	21½ P.M.

On this occasion the difference between the mean and apparent times of transit is shewn to be 14^m, and this is confirmed by the *Naut. Alm.*, where it is seen that the Equation of Time on February 19th is 14^m subtractive from mean time. So all things square in, which is satisfactory.

In the foregoing examples, it will be noticed that the observer is *at Greenwich*, but, theoretically speaking, sailors should apply a small correction depending upon longitude. This correction will be found in Table 23 of Raper, and is termed "acceleration." It is subtractive in west, and additive in east longitude. You will then have the *local* time of transit *at ship*. To exemplify this, let one of the previous examples be repeated.

What will be the mean time at ship of *Procyon's* meridian passage on February 19th, 1895, the longitude being 45° W.?

Mean time of transit at ship.

	H.	M.
R.A. of *Procyon* = its sidereal time of merid. pass. + 24 hrs. =	31	34
Sidereal time at Mean noon (N.A. page 21)	21	57
Interval in Sidereal time	9	37
Retardation (Raper, Table 24)		− 1½
Mean time of transit at Greenwich . . .	9	35½ P.M.
Acceleration for 45° W. (Raper, Table 23) .		− ½
Mean time of transit at ship . . .	9	35 P.M.*

Now, about the time that *Procyon* culminates, the twin brothers *Castor* and *Pollux* will do so likewise, and as the ob-

* Appendix I.

server is no longer supposed to be using a Transit instrument,* and as he *is* supposed to be totally unacquainted with the stars, it is two to one that, without some other means of identifying *Procyon*, he will pitch upon the wrong star, especially as all three lie on the same side (south) of the zenith. Well, Right Ascension has done its share, so we must call upon Declination to lend a hand.

Learning to recognise the stars.

Reference to the list shews that *Castor* lies 26½°, and *Pollux* 23° to the northward of *Procyon*; therefore, of the three bright stars passing the meridian close upon the same time, *Procyon* is far and away the nearest to the horizon. Moreover, the list shews it to be much the brightest. But to be a little more precise and make *quite* certain, we may determine its altitude as follows :—

Latitude of Greenwich	° 51·5 N.
Declination of *Procyon*	5·5 N.
Zenith distance	46·0 N.
	90
Altitude of *Procyon* on the meridian .	44°·0 S.

Therefore, on April 15th, at 5 hrs. 59 m. P.M., the student of the stars would face due South and look in the heavens for *Procyon* at a point midway between the horizon and the zenith. When it is remembered that from overhead to the horizon in any direction is 90°, it is apparent that but very little practice will enable the learner to *estimate* altitude with sufficient exactness for this purpose. It may assist him to remember, for comparison purposes, that from *Capella* to *Castor* is 30°; from *Altair* to *Antares* is 60°, or double the foregoing; and that from *Castor* to *Pollux* is 4½°.

Tabular time of meridian passage.

Table 27 of Raper is very handy, for what can be easier, if an unknown star be observed bearing north or south, than to note the time roughly and see which one corresponds to it. Suppose that it happened to be *Sirius*; well, *Sirius* once fairly recognised can never by any chance be forgotten. It is the very brightest

* Merely a superior telescope, mounted on trunnions in such wise that it shall only sweep the heavens in a true north and south line. The plane of this sweep, if continued downwards, would cut the earth into equal halves from pole to pole. Therefore, when rotated, the telescope describes a "vertical circle," which is the same as a "circle of altitude," and this again is a "great circle." It will be evident that the 'Transit' can be directed to objects at any meridional altitude due North or South of its position. The time is taken when the object crosses a vertical thread (or series of vertical threads) in the field of the instrument.

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star in all the heavens, and sparkles with many colours like a diamond. Just look at it with a pair of binoculars on a clear dark night.

Orion and his dogs.

Sirius, *Procyon*, and *Betelguese* form to the eye almost a perfect equilateral triangle, with sides of about 26°: taken in connection with their neighbours it is next to impossible to mistake them. *See* Plate V.

Now, a knowledge of one star paves the way to a knowledge of the others. Looking at the list it is seen that *Canopus*—another big fellow—passed the meridian 19m. in advance of *Sirius*, and should be visible nearly in the same line *if above the horizon.* But a second glance shews the declination of *Canopus* to be 52½° S., and as the observer is still at Greenwich in 51½° N., it is clear that *Canopus* must be some 14° below the southern horizon.

The gem of the south.

In brilliancy, *Canopus* surpasses every star, *Sirius* alone excepted. It is singular that, quite by accident, these two giants should have been selected to illustrate the writer's meaning, and singular that nature has put them side by side in the list.

Well, *Canopus* is disposed of by the process of exclusion, and the observer has learnt something, namely, that, being invisible, it is no longer possible to mistake for it any of those stars which *are* visible. This is termed *negative* knowledge, and is useful in its way.

Referring once more to the list, we find that *Betelguese* passed westward 51m. ahead of *Sirius*, and that its declination is 7½° N. Now, if Burdwood's Tables should be at hand, it is easy to find the approximate bearing of *Betelguese.* On page 212, with Latitude 51° of the *same* name as the declination, under 7°, and abreast 0hrs. 51m. on the right-hand side, will be found N. 162° W. = S. 18° W. Looking, therefore, 1½ points or so to the right of *Sirius*, and keeping in mind that *Betelguese* has a more northerly declination, there will be no difficulty in 'spotting' him. If Burdwood is not to the fore, Lecky's A B C Tables will serve nearly as well.

Star finding when on the meridian.

Here, be it said, that the best time to learn the stars is when they are on the meridian, and the nearer they are to the zenith so much the better. Their respective bearings *from each other* are then easier to determine, and they are looked at in the erect position: when low down in the east or west they are more or less on their beam-ends, and only their neighbours on one side of them are to be seen; whereas, when on the meridian at a fair altitude, their entire surroundings are in full view.

Now, with regard to their bearing and distance *from each other;* the average star book is rather loose and misleading as to the first, and not always correct as to the last. Let us make this perfectly plain, even at the expense of what in charter-party language is called a 'deviation.' The information acquired is to be regarded as salvage.

Inter-stellar bearings and distances.

When a ship is being navigated to a place so distant as to be *out of sight,* it is necessary to consult a chart for the course, and to have a compass by which to steer it. The chart in common use for such work is the one known as a Mercator. Its peculiarities have already been described in Chapter VII., but it is necessary just to touch upon them again in this connection. The following illustrations will be somewhat of the Jules Verne type.

An airy

Let a steamer bound from Cape Clear to Cape Race be navigated by a Mercator chart, and let the weather be so clear, the Captain's sight so keen, and the vantage point, on which he is perched, so much nearer the sky than the sea as to enable Newfoundland to be visible from the 'Emerald Isle.' Now, in the chapter above alluded to it has been pointed out that *on a Mercator chart* the ship's course between any two places is represented by a *straight* line; and *that this line makes the same angle with each meridian.* This is known as a Rhumb line or Loxodromic curve. Bearing this in mind, let the vessel be put upon the *chart* course for Cape Race. It will then be found, by the Argus-eyed skipper up aloft, that Cape Race, instead of being dead in a line with the stem, is away out on the starboard bow. But on hailing the deck he will be assured, by the officer of the watch, that she is 'right on her course.' Our sky-scraping Captain, determined not to be upset by such a trifle as the apparent shifting of a small island like Newfoundland, says, 'keep her so;' with the result that, as the voyage progresses, his ship's head is seen to be turning gradually towards Cape Race (though the *true* course steered has not once been altered), and finally points right at it.

Circular sailing.

It is obvious that the ship did not go straight from land to land, but that, on the contrary, she made a very decided and unnecessary sweep to the southward in order to cross each meridian at the same angle.

The Captain, anxious to 'make a passage,' does not see the fun of this 'circumbendibus' to the southward, and mentally decides that, on his return journey, he will try Great Circle sailing, which hitherto has seemed to him such a round-about business.

The conditions of weather, &c., being the same as before, he sets the *first*, or "initial," Great Circle course, and once again mounts aloft to the "crow's nest." This time, to his delight, he finds Cape Clear right ahead, and conning the vessel carefully himself, he, from time to time, sings out to the helmsman the necessary directions to keep it there independent of the shewing of the compass, which, however, is noted every two hours as usual, and duly entered in the Log. Having in this manner made a quick run and beaten the record, he descends to the deck satisfied that this time, at all events, the good ship has made a regular "Bee-line." On subsequently looking over the Mate's log-book, he is somewhat non-plussed to see that the *true* as well as the compass course had incessantly altered on the passage, though he knew from the evidence of his own optics that the ship's head had never once deviated from her destination. Thereupon our perplexed captain determines to consult "*Wrinkles*," and forthwith buys a copy. In it, he finds the following:—"*On a Mercator chart* the meridians are falsely represented as parallel, and consequently a pencil line drawn to shew the course between any two ports will cut each meridian at precisely the same angle; whereas *on the globe itself* the meridians converge to a mere point at either pole, their maximum of separation being at the Equator. *Not* being parallel to each other, a straight track *drawn on the earth's surface* (were it possible) *must cut each meridian at a different angle:* hence, in Great Circle sailing the *true course* continually changes, though the actual *direction* in which the ship is proceeding does *not* change."

Great Circle sailing.

"When in doubt,"—buy *Wrinkles*.

From this, it will be seen that the Navigator has to pay the penalty of extra distance for the luxury of using a Mercator chart.

In view of what has yet to come, it may be as well at once to thrash out the identity of an *Azimuth Circle* with a *Great Circle*. The reader must have patience. We will begin with a few homely definitions, which will be found handy generally.

ZENITH.—The point in the sky directly overhead. If a plumb-line could be hooked up there, the bob at this end would rest on the crown of one's cap; ('stand from under'). If extended downwards it would pass through the very centre of the globe, and eventually come out at the antipodes. Such a line would be a *vertical* line.* This is on the supposition that the globe is truly spherical.

Direction of Gravity.

* A *perpendicular* line is not necessarily a *vertical* line. When, for example, a line is at right angles to another, it is said to be perpendicular to it, no matter what its direction

NADIR.—If the Zenith be the point overhead, the Nadir, on the contrary, is the point at an infinite distance directly underfoot. The Zenith and Nadir may consequently be described as imaginary points representing, respectively, the elevated and depressed poles of the observer's horizon. Each individual has his own horizon, zenith, and nadir: as *he* moves, *they* move. Wherever he goes, they accompany him like his shadow.

In obedience to the unfailing law of Gravitation, all bodies are attracted towards the centre of the earth. Therefore, from New Zealanders being on the opposite side to ourselves, we stand feet to feet (but let us hope if a shindy ever comes we may stand 'shoulder to shoulder'); our zenith would be their nadir, and *vice versâ*. These terms are therefore purely relative.

Imperial Federation

GREAT CIRCLE.—A circle passing through the Zenith and Nadir, and cutting the horizon at right angles, is a Great Circle of the sphere or heavens. There is no reason why the *edge*, so to speak, of the circle should not be turned towards any part of the horizon; so long as its plane passes through the Zenith and Nadir, a Great Circle may look in any direction, and will divide the globe into two exactly equal parts. To do this it must of course pass through the centre.

The geometrical word 'plane' has been used in the last paragraph. Men who have not had the advantages of mathematical instruction sometimes fail to comprehend its meaning, and a reference to the dictionary leaves them as mystified as ever. In the case we are dealing with, the circle is supposed to be a flat vertical *surface without thickness*. Perhaps the nearest resemblance to such an ideal condition will be found in the tissue paper hoops which are held up by the clown at a circus, to be jumped through by *English equestrians with Italian names*. The well-stretched paper represents the *plane* of the circle. Let the learned not laugh.

A homely definition.

A VERTICAL CIRCLE, a CIRCLE OF ALTITUDE, and an AZIMUTH CIRCLE are first cousins; though their names are different they are strictly of the same family. They one and all pass through the zenith and nadir, and cut the horizon at right angles; they therefore belong to the *Great Circle* clan, members of which, like Scotchmen, are to be found go where you may.

The *Circle of Altitude* has only incidentally been referred to,

may be. *Perpendicular*, therefore, is a relative word, and ought not to be used without reference to something else. *Vertical* is an absolute word, and means the direction of the plumb-line.

so we will drop it as we would a poor relation, and carry on with the others. It may be said, 'Where in the name of Neptune is the author wandering to? Is not this a chapter on how to find the stars, and here we are Great Circle sailing away from them?'

Not so fast, dear reader, *if* you please; gently does it; all in good time. This little 'deviation' is merely intended to lead up to what follows, so now, with your leave, we will 'carry on.'

Reverting to the *Azimuth Circle*, it is evident that in its course from the zenith to the horizon it may pass through two stars; if an Azimuth Circle be a Great Circle, it follows that the portion between the two stars is an *arc* of this Great Circle, and its *angular* measure can readily be obtained by sextant. It would be spoken of as the 'distance' between the two stars, just as we speak of a 'Lunar distance,' which latter is merely the angular measure between the moon and a star, planet, or sun. The expression 'distance,' as used here, does not imply any *linear* measure. Two stars may be only one degree apart, and yet be separated in space by many billions or trillions of miles.

Angular and linear measure.

So far, we have dealt with two stars on the same side of the zenith, but the result would in no way be affected if they happened to be on opposite sides. Now the *azimuth* or *bearing* of the one star from the other is to all intents and purposes the *Great Circle Course* between any two places which may happen to lie vertically below them at the moment. *The expressions are interchangeable,* and to shew this yet more clearly, let us suppose that the plane of the Great Circle which passes through two stars in the sky *also* passes through two ports on the surface of mother earth. In such case the direction of the ports from each other would correspond to the direction of the stars from each other. For the purpose of our illustration, which, however, will not be quite so complete as the above, we will select the well-known stars *Capella* and *Dubhe*, and the equally well-known sea-ports of Rochefort on the Biscayan coast of France, and Christiansund in Norway.

Star charts.

The course and distance between two places on the globe, however far asunder, may be ascertained from the chart; but in the case of widely separated stars, some other plan is mostly necessary. It is true, charts of the heavens without number are constructed, and on various principles, according to requirements, but should these charts embrace a fairly large area, they all depict more or less falsely the aspect of the heavens. In some Star Atlases the Mercatorial construction is employed for the portion of the heavens lying as much as 40° or thereabouts on each side of the equator; but a map on this principle is quite unsuited for star delineation. The best method is the one known as the *Conical;* near the equator it becomes *Cylindrical.* **Delineation of the celestial sphere.**

Now for the demonstration.

On a Mercator chart of the stars, the bearing between *Capella* and *Dubhe* is N. 72° E., and the angular distance is 53° nearly. The return bearing would of course be S. 72° W., and the angular distance the same as before.

Now, any one acquainted with *Capella* would be very likely to fall into the error of supposing that this knowledge would at once enable him to find *Dubhe.* It would not. To test this, let the learner put on his 'seven-league boots' and travel in fancy to Rochefort. The latitude of this port is the same as the declination of *Capella,* and, consequently, whenever *Capella* is on the meridian of Rochefort it is in the zenith of that place, or directly overhead, when of course a bearing observed at Rochefort would correspond to one observed at *Capella.* At that precise moment, then, let the observer look in the sky for *Dubhe* on the bearing of N. 72° E., and at a distance from *Capella* (measured by sextant) of 53°.

As the heavens are certainly not laid out before his gaze on the principle of a Mercator chart, it is a foregone conclusion that the searcher will search in vain. He will, in fact, be looking exactly 34°, or three whole points, to the eastward of where he ought to look. At the moment, however, that *Capella* is in the zenith of Rochefort, the Great Circle Course between the two stars will give the real bearing of *Dubhe,* both from *Capella* and from the observer. This happens to be N. 37¾° E., and the angular distance 49¼°. There is therefore a vast difference. **Mystification.** **Initial course.**

Before proceeding further, it must be repeated that the *Great Circle Course* between any two objects, whether in the sky or on the globe, is to all intents and purposes the same as the *true azimuth* between those objects or places, or, in other words, the azimuth of a heavenly body may be considered as the Great Circle Course to the place where such heavenly body is vertical at the moment. This is still further elucidated in the chapter on "Shaping the Course," to which the reader if he chooses may refer, after he has mastered this one.

Next imagine the observer to be transported to Christiansund. The latitude of this place is nearly the same as the declination of *Dubhe,* so when the latter is on the meridian of Christiansund it so we will drop it as we would a poor relation, and carry on with the others. It may be said, 'Where in the name of Neptune is the author wandering to? Is not this a chapter on how to find the stars, and here we are Great Circle sailing away from them?'

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Next imagine the observer to be transported to Christiansund. The latitude of this place is nearly the same as the declination ot *Dubhe,* so when the latter is on the meridian of Christiansund it will practically be plumb overhead. At this precise moment let our friend of the inquiring turn look for *Capella* on its mercatorial bearing of S. 72° W. As before, he will be doomed to disappointment. *Capella* will really bear from him N. 66½° W., or 3¾ points more to the northward, whilst the sextant distance will continue to be 49¼°.

Initial course.

Dissimilarity of forward and return bearings.

Now please notice the remarkable difference. The return mercatorial bearing is to the *southward* and westward, whereas the Great Circle Course, which is the real *visible* bearing or *true azimuth*, is to the *northward* and westward.

Notice further that the G. C. Course, or visible bearing of *Capella* from *Dubhe* (N. 66½° W.), is not the reverse—or anything near it—of *Dubhe* from *Capella* (N. 37¾° E.) Why is this? Because in each case the course is measured or laid off from the meridian passing through Rochefort and Christiansund respectively, and as the two courses are a long way from agreeing with each other, does it not again prove—if proof were wanting—that on the globe the meridians are not parallel, as the Mercator construction assumes them to be. The meridian then, of the observer, is the base from which all true bearings are calculated.

The illustration would have been more satisfactory if the difference of Right Ascension of *Capella* and *Dubhe* had happened to be the same as the difference of longitude between Rochefort and Christiansund, because in that case the two stars would occupy relatively the same places in the heavens that the two ports do on the earth, and *Capella* would have been on the meridian of Rochefort at the same instant of time that *Dubhe* was on the meridian of Christiansund. Had this been so, the Great Circle courses between the ports would be identical with the G. C. courses between the stars.

To go straight, course must alter.

The courses here given are only the *initial* courses, or those used at the start from either end. As already explained, though the *direction* never changes, the *course* requires to be constantly altered on a voyage from one place to another: the *amount* of alteration depends upon a variety of circumstances, such as the vessel's speed, the direction in which she is steering, and the latitude. If steering in an easterly or westerly direction, the nearer the pole the more rapid the change. Yet another illustration :—

Supposing our globe to be a hollow, transparent glass sphere, and an observer somehow to be located exactly at its centre; then a sextant angle between *any* of the heavenly bodies—no matter what their direction from the observer or from each other—would be an arc of a Great Circle. It is evident that the same would apply to places or ports on the surface of the globe. Let Rochefort and Christiansund each be represented by a tiny ring scratched on the glass. Then, had the Right Ascensions permitted, the observer looking at Christiansund from the middle of the earth would see *Dubhe* through the centre of the ring when it came to the meridian of that place, and at the same instant *Capella* would be seen through and beyond Rochefort.

Great Circles—Celestial and Terrestrial.

To avoid complications, let us put on one side this last phase of the question, and for the present, at all events, deal solely with *celestial* objects.

It does not follow that *all* celestial angles measured by an observer at the centre of the earth would, if *re*-measured on his return to the surface, *there* prove to be equally arcs of Great Circles. Indeed, with the moon and planets, this would seldom be the case.

To get the *true* or Nautical Almanac 'distance' between, say, the Moon and Mars, a reduction to the centre of the earth is necessary: this forms part of the calculation of a 'Lunar,' spoken of technically as 'clearing the distance.'

But the case of two *stars* is quite different. Their *actual* distance from us is so vast that it is all one whether you look at them from the centre or from the surface of the earth. There is no displacement, or in other words, no parallax; the sextant angle between them would be *precisely* the same in both cases, and could properly be treated as the arc of a Great Circle.

One lesson to be derived from the foregoing trips to France and Norway is that, if you are star-chasing, and take from a 'common or garden' atlas the relative bearing of any two stars, you must not always expect to find corroboration in nature. An approach to it, however, will be made in the case of stars with small declinations: for example, the Mercatorial bearing of *Betelguese* from *Procyon* would correspond, within a degree or two, with the Great Circle bearing or true azimuth; and the angular distance would be practically the same for each. The actual sky bearing of *Procyon* from *Betelguese* is S. 86¾° E., and the distance 26°.

Star Atlases.

To 'make a case,' as the lawyers say, *Capella* and *Dubhe* were specially selected, but, in justice to published star charts, it may be stated that the writer does not know of any in which these two high declination stars would be shewn on the Mercator projection. The illustration, however, is otherwise instructive, and brings the writer's point more forcibly home to the mind.

Inter-stellar bearings.

Now, it is impossible for anyone to skip about like a kangaroo from place to place, to bring certain stars vertically overhead in order to trace from them the bearing of other stars; and as, moreover, it is only for that precise moment that the bearing holds good *to the observer*, it will not be worth while to trouble the reader with inter-stellar bearings, except now and again in a general way.

The earth revolves, and not the sky.

To make this last point plainer, take the case of any conspicuous circumpolar stars lying fairly close together. The Southern Cross and Centaurs will do admirably. To an observer in the latitude of the Cape of Good Hope, when the Cross is on the meridian *above* the pole, the Centaurs lie to the left or eastward of it; when on the meridian *below* the pole, they lie to the right or westward of it. Meanwhile, these two groups have not in any way changed *relatively to each other;* but, owing to the earth's half revolution on its axis, they have changed *so far as the observer is concerned.* To put it more correctly, it is *he* who has changed, not *they.* At the time of the lower culmination of the Cross, the observer is standing on his head as compared with his position 12 hours previously. Between the extremes here given, the observer, supposing him able to watch continuously, would witness all the intermediate changes of direction as the stars referred to appeared to revolve round the south pole.

If, then, a beginner should desire to find a circumpolar star by its bearing from another which he knows, it will be best to make the attempt when the latter is on the meridian *above* the pole, and the nearer to the zenith the greater the likelihood of success. At other times it may be exceedingly difficult.

Inter-stellar Distances.

The *Angular Distances* between the various stars remain pretty much the same under all circumstances, and can therefore be measured by sextant at any time when visible. This being so, the correct distances between the principal ones are given at the end of this chapter. A beginner can by this means test his proficiency with the sextant, recollecting, however, that owing to the inequality of refraction, and the *small* secular change among the stars themselves, he must not expect *exact* correspondence. If he can make his sextant value come within 3′ or 4′ of the book value, he will not be doing so badly, especially in those cases where the sextant has to be held face downwards. A measure between a star near the zenith and one near the horizon will be most affected by refraction. The same pair, when equidistant from the zenith, will give a slightly different and more correct measure.

What has been termed the *Astronomical* method of finding the stars applies equally to the Planets, but, from their being 'Wanderers,' the *Naut. Alm.* must be consulted for their positions on any given date. From the same cause, of course, it is impossible to give their angular distances from each other. Sometimes they are quite close together (conjunction), and sometimes quite far apart. **Inter-Planetary distances.**

There are only four planets of service to the mariner; taking them in the order of their distance from the sun, they are—VENUS (67 millions), MARS (142 millions), JUPITER (483 millions), and SATURN (886 millions). They will be found in the *Naut. Alm.* for 1895, between pages 234 and 265. VENUS and JUPITER are more brilliant than *Sirius*, and MARS is decidedly reddish in colour. He is often alluded to as 'Ruddy Mars.' These three, therefore, take but little finding. SATURN is much less noticeable, and requires to be treated as an unknown star by turning up its Declination and Right Ascension. The fact of the declinations of these four planets being always within the limits of 30° N. and 30° S., gives one a general idea as to their position in the heavens: for example, an astronomer at Greenwich, if he wished to find Jupiter on the meridian, would certainly not direct his gaze to the northward. He would know it *must* lie south of him. **To recognize the planets.**

Stars mostly twinkle, *but not always*, and least when near the zenith. Those of the larger magnitudes twinkle more than the smaller ones. Planets, on the contrary, mostly shine with a steady lustre; but here again there are exceptions. The condition of the atmosphere, combined with the altitude of the body, has a considerable voice in the matter. It is stated that at the Lick Observatory, in California, where the atmosphere is remarkably tranquil, and the instruments situated some 4,000 and odd feet above the sea, stars do not twinkle at all. **Twinkling.**

As already mentioned, VENUS and JUPITER are so exceptionally bright as to render it altogether impossible to take them for fixed stars; in fact, each will cast a perceptible shadow, and at favourable times will even give sufficient light to read a newspaper. It is not to be wondered at, then, if the average observer should occasionally get 'mixed' as to which is which. It is, however, hardly necessary to appeal to the Almanac when in doubt, as star in all the heavens, and sparkles with many colours like a diamond. Just look at it with a pair of binoculars on a clear dark night.

Orion and his dogs.

Sirius, Procyon, and *Betelguese* form to the eye almost a perfect equilateral triangle, with sides of about 26°: taken in connection with their neighbours it is next to impossible to mistake them. *See* Plate V.

Now, a knowledge of one star paves the way to a knowledge of the others. Looking at the list it is seen that *Canopus*—another big fellow—passed the meridian 19m. in advance of *Sirius*, and should be visible nearly in the same line *if above the horizon.* But a second glance shews the declination of *Canopus* to be 52½° S., and as the observer is still at Greenwich in 51½° N., it is clear that *Canopus* must be some 14° below the southern horizon.

The gem of the south.

In brilliancy, *Canopus* surpasses every star, *Sirius* alone excepted. It is singular that, quite by accident, these two giants should have been selected to illustrate the writer's meaning, and singular that nature has put them side by side in the list.

Well, *Canopus* is disposed of by the process of exclusion, and the observer has learnt something, namely, that, being invisible, it is no longer possible to mistake for it any of those stars which *are* visible. This is termed *negative* knowledge, and is useful in its way.

Referring once more to the list, we find that *Betelguese* passed westward 51m. ahead of *Sirius*, and that its declination is 7½° N. Now, if Burdwood's Tables should be at hand, it is easy to find the approximate bearing of *Betelguese.* On page 212, with Latitude 51° of the *same* name as the declination, under 7°, and abreast 0hrs. 51m. on the right-hand side, will be found N. 162° W. = S. 18° W. Looking, therefore, 1½ points or so to the right of *Sirius*, and keeping in mind that *Betelguese* has a more northerly declination, there will be no difficulty in 'spotting' him. If Burdwood is not to the fore, Lecky's A B C Tables will serve nearly as well.

Star finding when on the meridian.

Here, be it said, that the best time to learn the stars is when they are on the meridian, and the nearer they are to the zenith so much the better. Their respective bearings *from each other* are then easier to determine, and they are looked at in the erect position: when low down in the east or west they are more or less on their beam-ends, and only their neighbours on one side of them are to be seen; whereas, when on the meridian at a fair altitude, their entire surroundings are in full view.

Now, with regard to their bearing and distance *from each other;* the average star book is rather loose and misleading as to the first, and not always correct as to the last. Let us make this perfectly plain, even at the expense of what in charter-party language is called a 'deviation.' The information acquired is to be regarded as salvage. **Inter-stellar bearings and distances.**

When a ship is being navigated to a place so distant as to be *out of sight,* it is necessary to consult a chart for the course, and to have a compass by which to steer it. The chart in common use for such work is the one known as a Mercator. Its peculiarities have already been described in Chapter VII., but it is necessary just to touch upon them again in this connection. The following illustrations will be somewhat of the Jules Verne type.

Let a steamer bound from Cape Clear to Cape Race be navigated by a Mercator chart, and let the weather be so clear, the Captain's sight so keen, and the vantage point, on which he is perched, so much nearer the sky than the sea as to enable Newfoundland to be visible from the 'Emerald Isle.' Now, in the chapter above alluded to it has been pointed out that *on a Mercator chart* the ship's course between any two places is represented by a *straight* line; and *that this line makes the same angle with each meridian.* This is known as a Rhumb line or Loxodromic curve. Bearing this in mind, let the vessel be put upon the *chart* course for Cape Race. It will then be found, by the Argus-eyed skipper up aloft, that Cape Race, instead of being dead in a line with the stem, is away out on the starboard bow. But on hailing the deck he will be assured, by the officer of the watch, that she is 'right on her course.' Our sky-scraping Captain, determined not to be upset by such a trifle as the apparent shifting of a small island like Newfoundland, says, 'keep her so;' with the result that, as the voyage progresses, his ship's head is seen to be turning gradually towards Cape Race (though the *true* course steered has not once been altered), and finally points right at it. **An airy** **Circular sailing.**

It is obvious that the ship did not go straight from land to land, but that, on the contrary, she made a very decided and unnecessary sweep to the southward in order to cross each meridian at the same angle.

The Captain, anxious to 'make a passage,' does not see the fun of this 'circumbendibus' to the southward, and mentally decides that, on his return journey, he will try Great Circle sailing, which hitherto has seemed to him such a round-about business.

Great Circle sailing.

The conditions of weather, &c., being the same as before, he sets the *first*, or "initial," Great Circle course, and once again mounts aloft to the "crow's nest." This time, to his delight, he finds Cape Clear right ahead, and conning the vessel carefully himself, he, from time to time, sings out to the helmsman the necessary directions to keep it there independent of the shewing of the compass, which, however, is noted every two hours as usual, and duly entered in the Log. Having in this manner made a quick run and beaten the record, he descends to the deck satisfied that this time, at all events, the good ship has made a regular "Bee-line." On subsequently looking over the Mate's log-book, he is somewhat non-plussed to see that the *true* as well as the compass course had incessantly altered on the passage, though he knew from the evidence of his own optics that the ship's head had never once deviated from her destination. Thereupon our perplexed captain determines to consult "*Wrinkles*," and forthwith buys a copy. In it, he finds the following:—"*On a Mercator chart* the meridians are falsely represented as parallel, and consequently a pencil line drawn to shew the course between any two ports will cut each meridian at precisely the same angle; whereas *on the globe itself* the meridians converge to a mere point at either pole, their maximum of separation being at the Equator. *Not* being parallel to each other, a straight track *drawn on the earth's surface* (were it possible) *must cut each meridian at a different angle:* hence, in Great Circle sailing the *true course* continually changes, though the actual *direction* in which the ship is proceeding does *not* change."

"When in doubt,"—buy *Wrinkles*.

From this, it will be seen that the Navigator has to pay the penalty of extra distance for the luxury of using a Mercator chart.

In view of what has yet to come, it may be as well at once to thrash out the identity of an *Azimuth Circle* with a *Great Circle*. The reader must have patience. We will begin with a few homely definitions, which will be found handy generally.

Direction of Gravity.

ZENITH.—The point in the sky directly overhead. If a plumb-line could be hooked up there, the bob at this end would rest on the crown of one's cap; ('stand from under'). If extended downwards it would pass through the very centre of the globe, and eventually come out at the antipodes. Such a line would be a *vertical* line.* This is on the supposition that the globe is truly spherical.

* A *perpendicular* line is not necessarily a *vertical* line. When, for example, a line is at right angles to another, it is said to be perpendicular to it, no matter what its direction

NADIR.—If the Zenith be the point overhead, the Nadir, on the contrary, is the point at an infinite distance directly underfoot. The Zenith and Nadir may consequently be described as imaginary points representing, respectively, the elevated and depressed poles of the observer's horizon. Each individual has his own horizon, zenith, and nadir: as *he* moves, *they* move. Wherever he goes, they accompany him like his shadow.

In obedience to the unfailing law of Gravitation, all bodies are attracted towards the centre of the earth. Therefore, from New Zealanders being on the opposite side to ourselves, we stand feet to feet (but let us hope if a shindy ever comes we may stand 'shoulder to shoulder'); our zenith would be their nadir, and *vice versâ*. These terms are therefore purely relative. **Imperial Federation**

GREAT CIRCLE.—A circle passing through the Zenith and Nadir, and cutting the horizon at right angles, is a Great Circle of the sphere or heavens. There is no reason why the *edge*, so to speak, of the circle should not be turned towards any part of the horizon; so long as its plane passes through the Zenith and Nadir, a Great Circle may look in any direction, and will divide the globe into two exactly equal parts. To do this it must of course pass through the centre.

The geometrical word 'plane' has been used in the last paragraph. Men who have not had the advantages of mathematical instruction sometimes fail to comprehend its meaning, and a reference to the dictionary leaves them as mystified as ever. In the case we are dealing with, the circle is supposed to be a flat vertical *surface without thickness*. Perhaps the nearest resemblance to such an ideal condition will be found in the tissue paper hoops which are held up by the clown at a circus, to be jumped through by *English equestrians with Italian names*. The well-stretched paper represents the *plane* of the circle. Let the learned not laugh. **A homely definition.**

A VERTICAL CIRCLE, a CIRCLE OF ALTITUDE, and an AZIMUTH CIRCLE are first cousins; though their names are different they are strictly of the same family. They one and all pass through the zenith and nadir, and cut the horizon at right angles; they therefore belong to the *Great Circle* clan, members of which, like Scotchmen, are to be found go where you may.

The *Circle of Altitude* has only incidentally been referred to,

may be. *Perpendicular*, therefore, is a relative word, and ought not to be used without reference to something else. *Vertical* is an absolute word, and means the direction of the plumb-line.

there are points of dissimilarity which should generally prevent a mistake. For example, VENUS is an *inferior* planet, that is to say, her orbit lies between the earth and the sun at a distance from the latter of 67 millions of miles, as compared with our own distance of 93 millions. This proportion does not permit of VENUS having a greater *angular* distance, east or west of the sun, than 47°, equal to 3 hrs. 8 m. in time. Astronomers speak of this as 'Elongation.' Therefore VENUS, though visible in the evening or morning, sticks so close to the sun as never to be visible at *night*, as we understand the word in these latitudes.*

Venus enamoured of the sun.

On the other hand, the orbit of JUPITER lies a long way *outside* that of the earth, his distance from the sun being no less than 483 millions of miles!! This permits of 'Mighty Jove' taking *any* angular position as regards the earth and the sun, and, consequently, he may be visible at any hour of the night.

Planetary movements in the sky.

Again, owing to his vastly greater distance from us, the movement of JUPITER on the still further background of the stars is very much slower than VENUS: for instance, on the morning of February 6th, 1892, these two planets were in conjunction, JUPITER being hidden behind VENUS. When this interesting phenomenon occurred, their mutual Declination and Right Ascension were 4° 43′ S. and 23 hrs. 27½ m., but on January 1st preceding, their respective positions were as under:—

	DECLIN. ° ′		R. ASCEN. H. M.	
VENUS . .	20 19 S.	Coming North.	20 37	Increasing.
JUPITER . .	7 33 S.		23 1	

In the interval VENUS had moved north about 16°, whilst JUPITER had done but 3° in the same direction. VENUS had also covered nearly 3 hrs. of R.A., whilst JUPITER had barely done 30 m. Though JUPITER had had such a long start, VENUS caught him up in little over a month. If VENUS be watched for a few evenings, her motion among the stars is easily perceived.

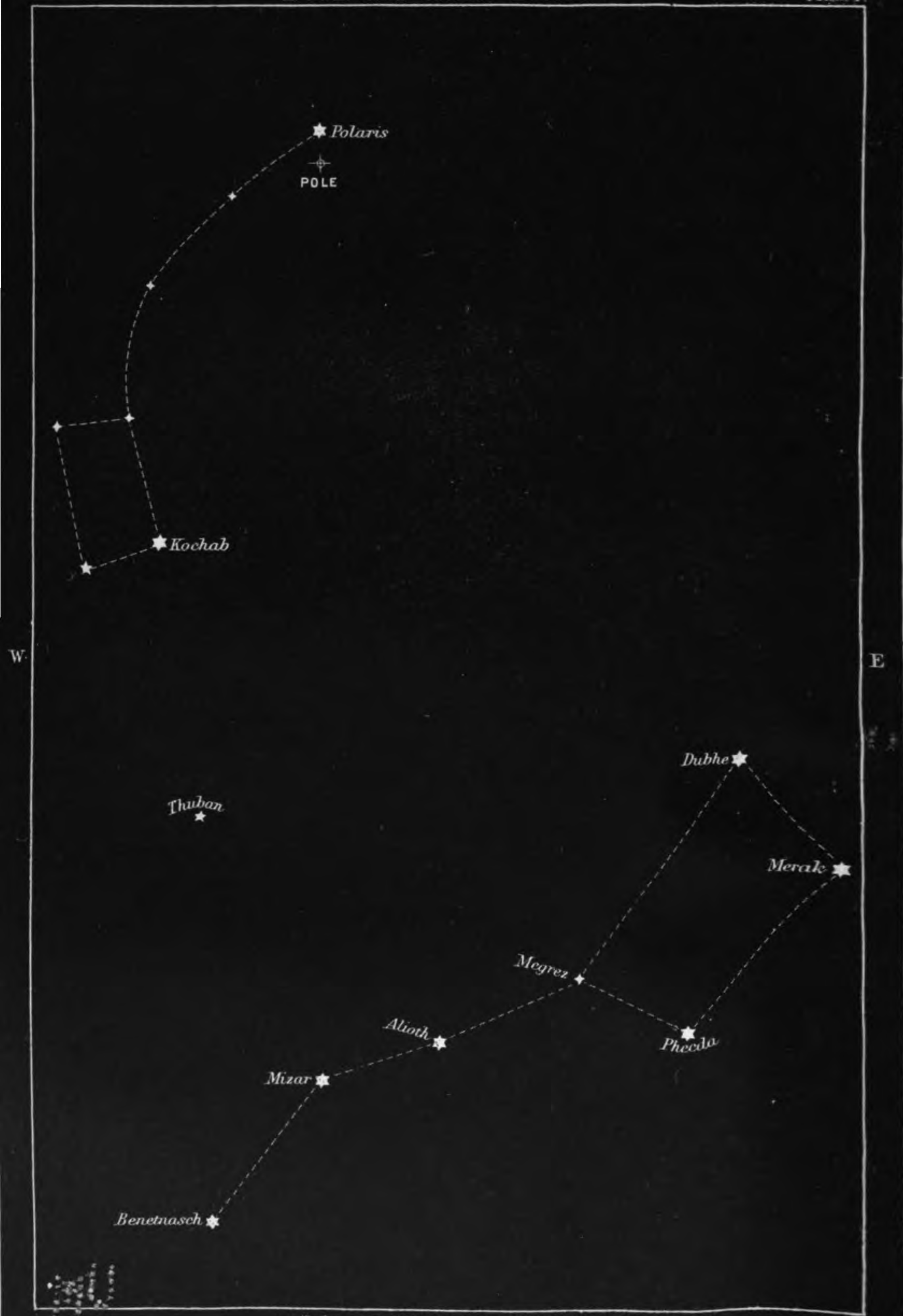
The learner ought by this time to have a fair idea of the *astronomical* method, so we will pass on to the other, and it is this one which will probably find most favour with practical men.

Whatever the constellations may have been like in ancient times, an observer of to-day will find it impossible to trace in the

* Hence VENUS is commonly known as the 'morning and evening star,' or as *Lucifer* and *Vesper*.

LITTLE AND GREAT BEARS

Plate I.



Below the Pole looking NORTH

TO FACE PAGE 345

sky the various figures which groups of stars are, or were, supposed to represent.

It is better at once to throw over these fantastic figures as so much imaginary rubbish.

There are only two—Cassiopeia's Chair and the Southern Cross—that in any way deserve their name. The *Chair* is far from being an easy one, and the *Cross* is very disappointing to sentimental people who see it for the first time.

Constellations.

Now although most men would fail to recognise such fanciful images as the Fox and the Goose, Noah's Dove, the Winged Horse, &c., they could not but perceive on the most casual inspection that certain star groups had forms, mostly geometrical, of some kind or another. By first of all learning the most conspicuous of these, and then taking them as starting points, it becomes quite easy to trace the others.

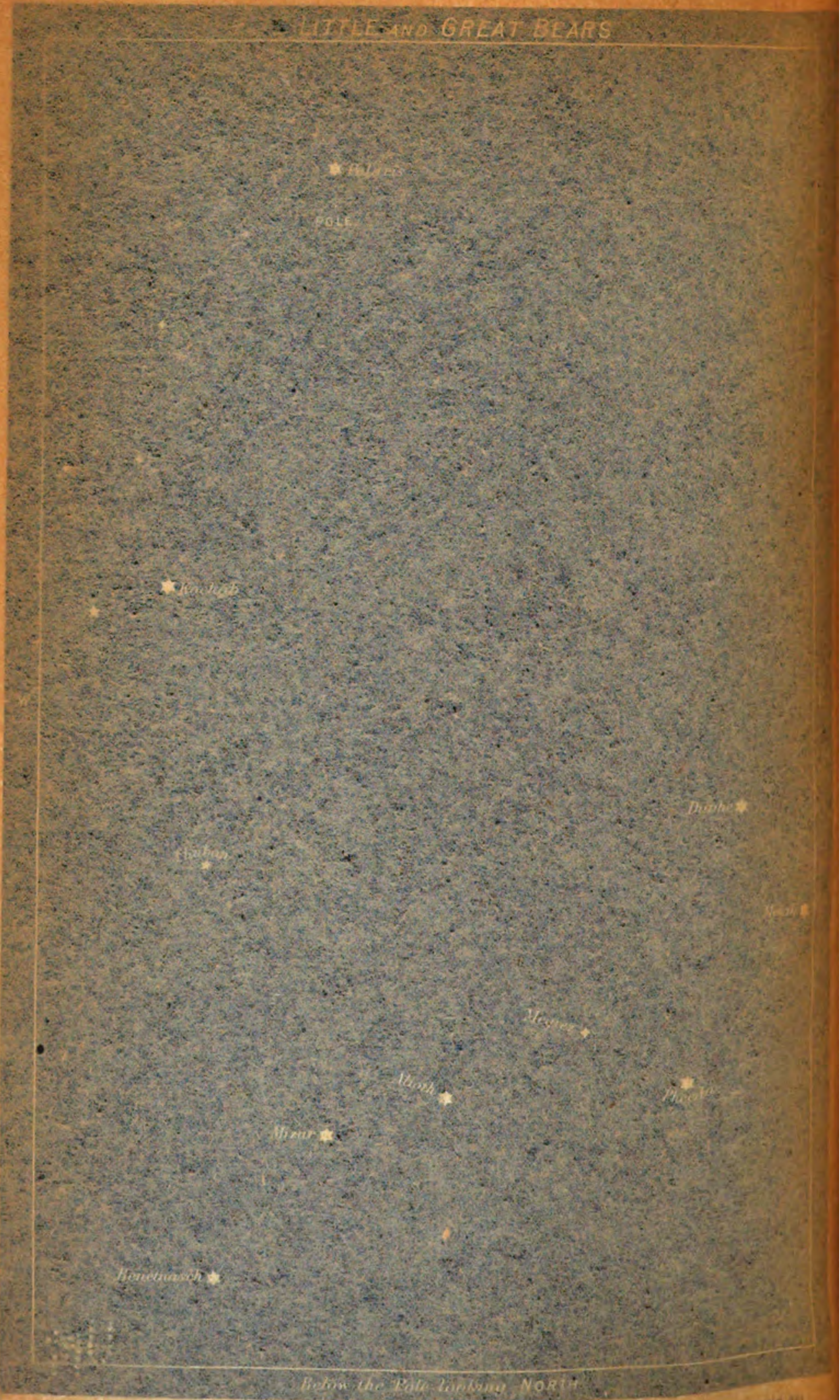
This, then, is the *astrographical* method, and to practise it on a fine night during one's watch on deck is not an unprofitable way of passing the time. It is also an excellent antidote to drowsiness; much better than putting one's head in a bucket of water, a remedy, the writer, when a youngster, confesses to have tried once or twice when becalmed near the 'Line,' with the canvas lazily flapping against the masts, and the yard parrels chanting a lullaby for want of grease.

Now for the ten groups selected as sky marks by which to find the more isolated stars in the list, beginning with the most northern group and working south.

Star groups.

LITTLE BEAR is made up of seven or eight stars, though only three are worth notice. *Polaris*, in the tip of the tail, is chief of the crowd, but in any case takes front rank as the 'North Star.' It is a standard star of the 2nd mag.; β and γ are known as the 'Guards'; the remainder are a poor lot. The parallax of *Polaris* is 0"·078, which means a light journey of 42 years, and a distance of 245 billions of miles.

GREAT BEAR, with an impossible tail for a bear, makes an infinitely better 'PLOUGH.' It is composed of seven stars of nearly equal brightness, and is described in detail on page 383. Quite near to ζ, the second star from the end of the handle, is *Alcor*, or 'the test.' There is little reason to complain of the sight of any one who can see *Alcor* with the naked eye; it must be passably good, but need not be remarkably so. The Great Bear in



Below the Pole looking NORTH

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The 'Plough.'

		Parallax. ″	Light years.	Distance in miles.	Magnitudes.
α Urs. Maj.	*Dubhe*	0·046	71	416 billions	1·89
β „ „	*Merak*	·080	41	239 „	2·17
γ „ „	*Phecda*	·099	33	193 „	2·30
δ „ „	*Megrez*	not yet ascertained			3·20 approx.
ε „ „	*Alioth*	·081	40	236 „	1·80
ζ „ „	*Mizar*	not yet ascertained			2·00 approx.
η „ „	*Benetnasch*	immeasurable			1·77

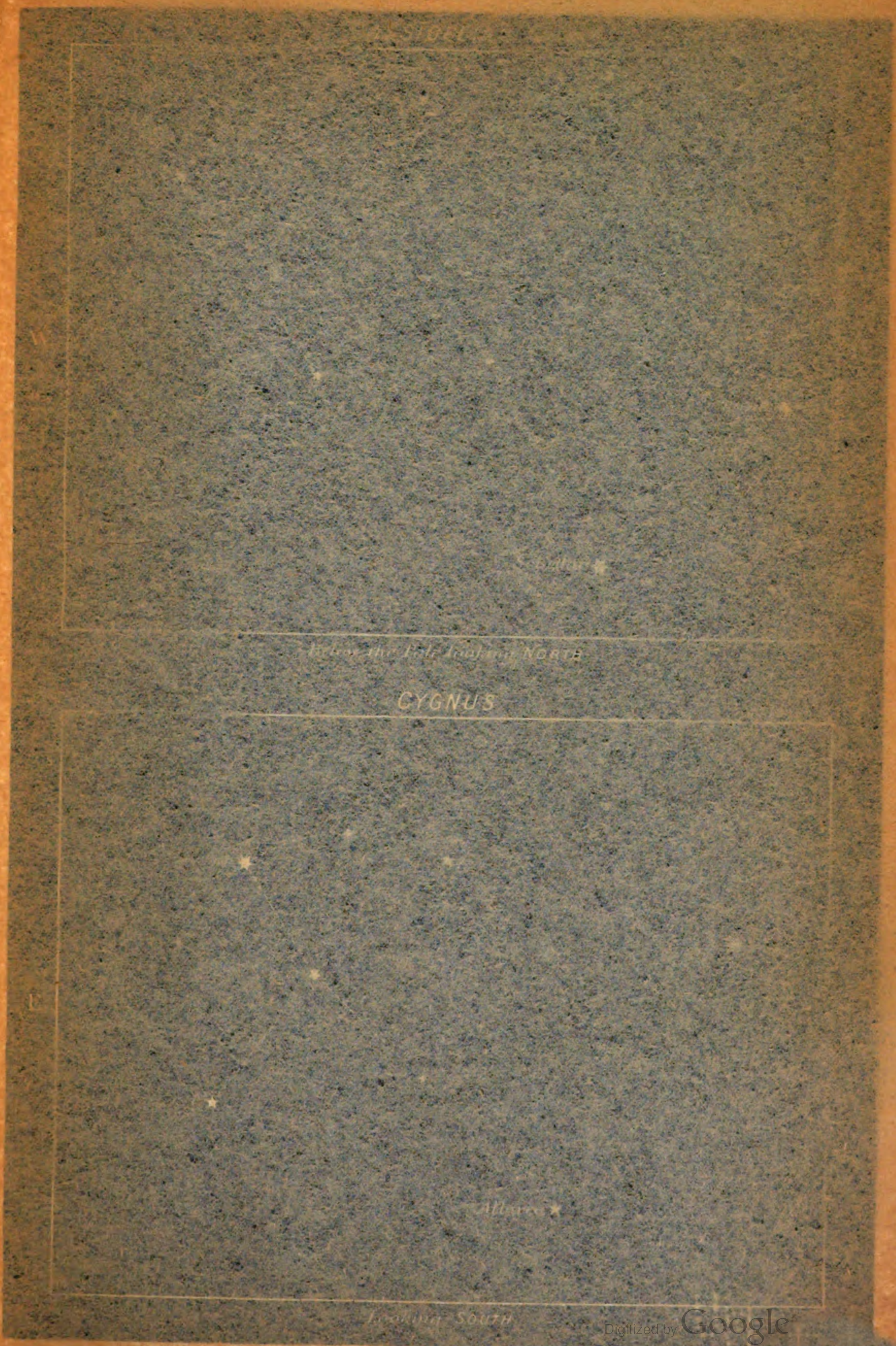
It will be seen from this that, though in the same constellation, these stars have no physical connection with each other. *Dubhe* and *Benetnasch* are approaching the earth at approximately 46 and 32 miles a second, respectively; and the remaining five are receding at about 20 miles a second.

Cassiopeia's Chair is moored in space on the opposite side of *Polaris* to what the 'Plough' is, and at about the same distance from it. The five stars make a straggling W, and a worse M, according to which side is uppermost. As a chair it is very ricketty, and of the back-breaking type. Some gifted people even see a footstool; but then some people would see anything anywhere, whilst others at times are unable even to see a hole in a 40-foot ladder. The constellation does not set in these latitudes.

Individual perceptive faculties.

Cygnus is Latin for 'Swan,' but it might just as well be Greek or Sanscrit, for the swan is invisible no matter how you may twist your neck to look at it. Cygnus makes a goodish cross lying on its side when rising or setting, but it also makes a capital boy's kite. First, consider it as a cross. From head to foot along the middle line there are four stars; the two more northerly being fairly respectable in brilliancy, and forming the head of the cross, naturally look down upon the two dimmer stars at the foot. The transverse stars are three in number, including one of those already mentioned, because the centre star counts in both directions. These six constitute the cross, which is 22° 18′ in length, and 16° 7′ from side to side.

To make a kite or cross-bow, look right and left of the star at the head, and a faintish star will be discerned, forming a curve with it and those at the side. As a kite, therefore, there are eight stars: the two at the foot, and the two helping to form the bow, are the faintest of the lot. Cygnus lies between *Vega* and the 'Square of Pegasus.'


Below the Pole looking NORTH
CYGNUS
Altair
Looking SOUTH

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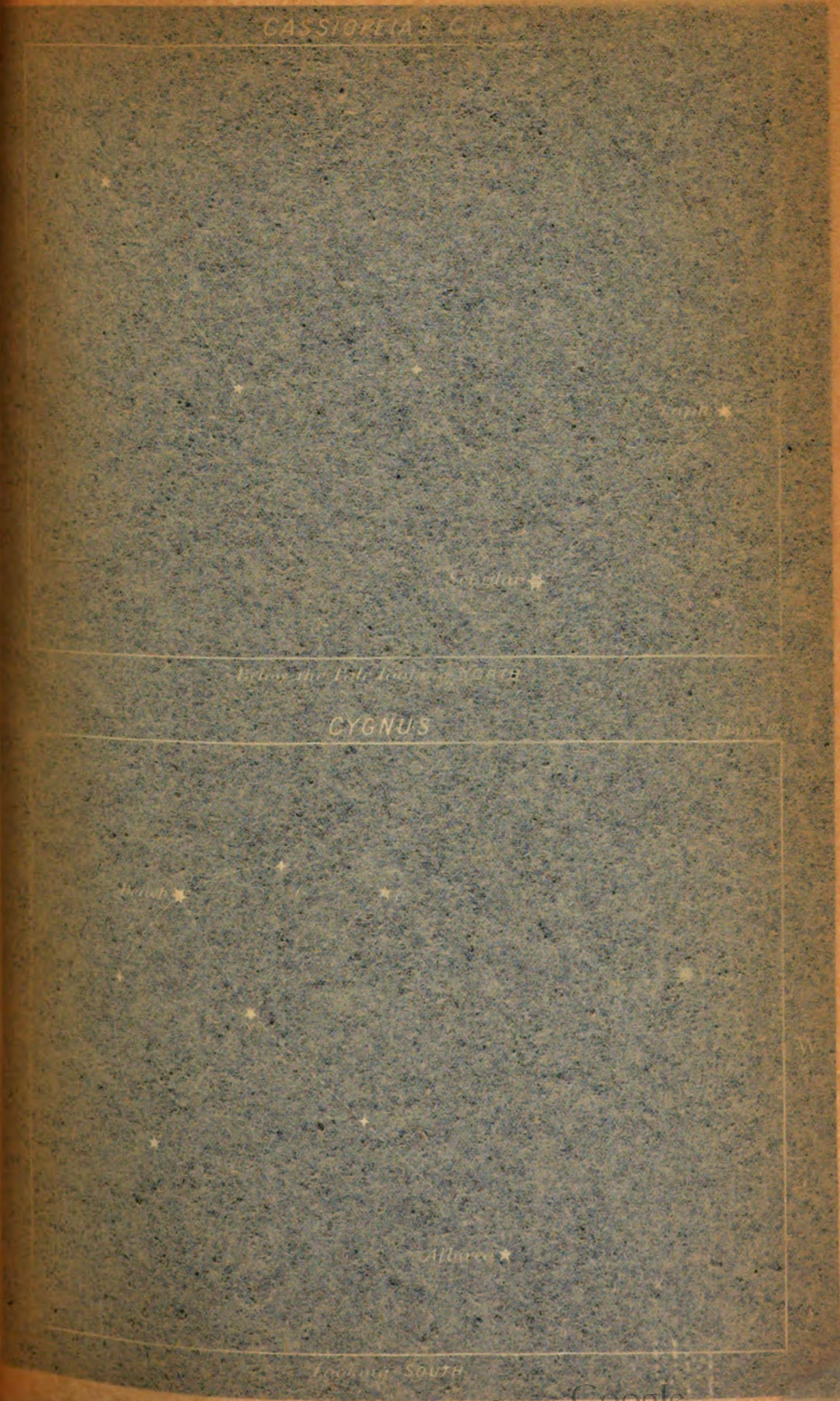

TO FACE PAGE

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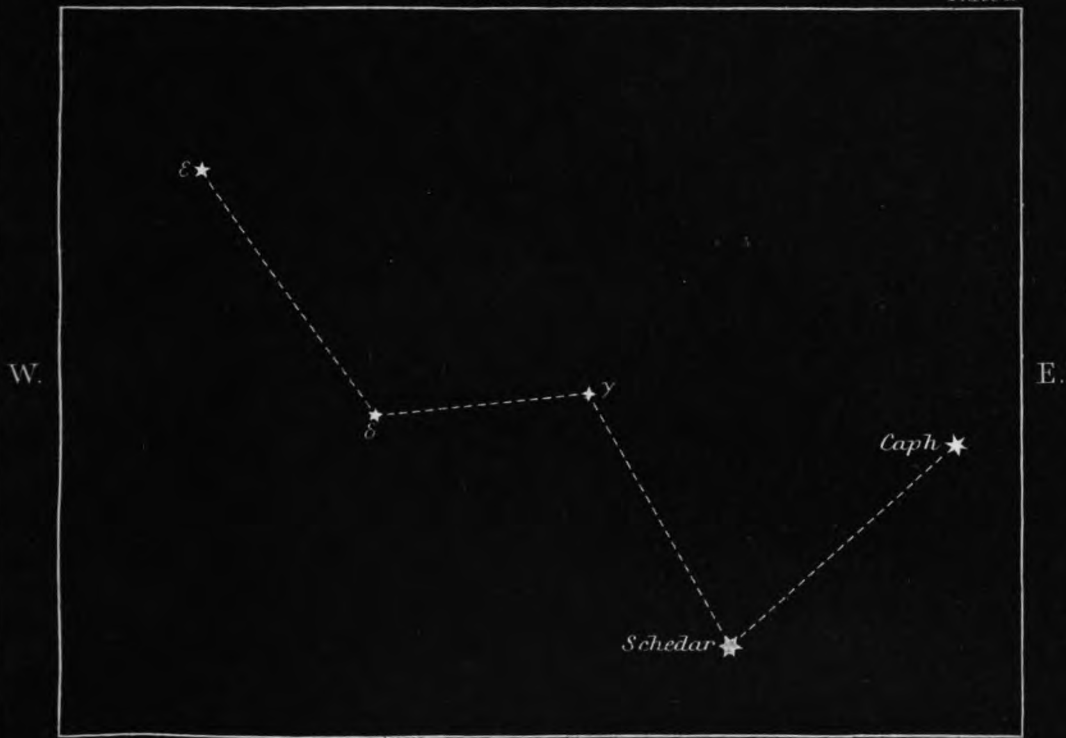
CASSIOPEIA'S CHAIR

Plate II



Below the Pole looking NORTH

CYGNUS

Plate III

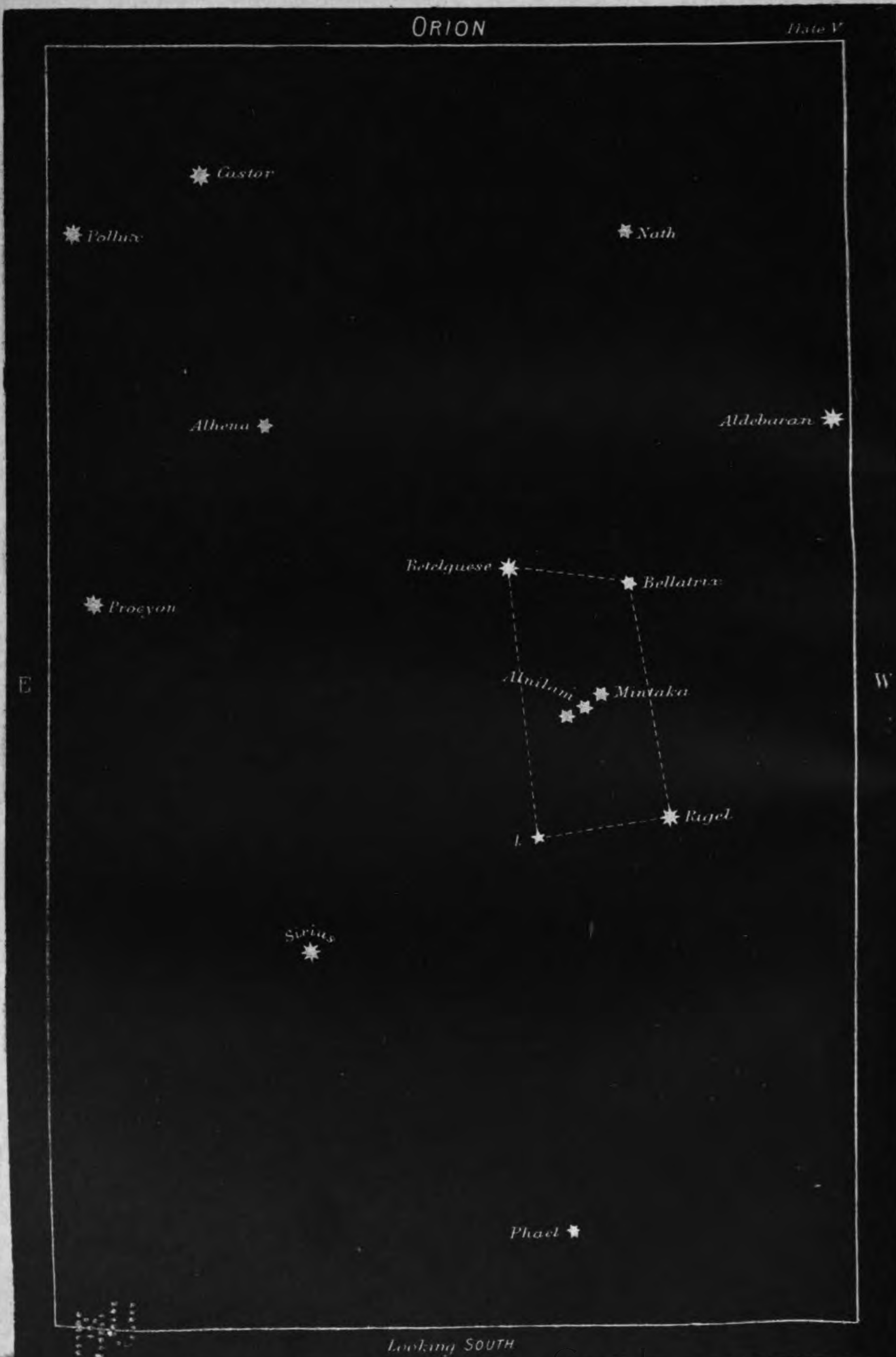
Looking SOUTH

TO FACE PAGE 246

PEIA'S CHAIR. PEGASUS

JACENT CONSTELLATIONS.

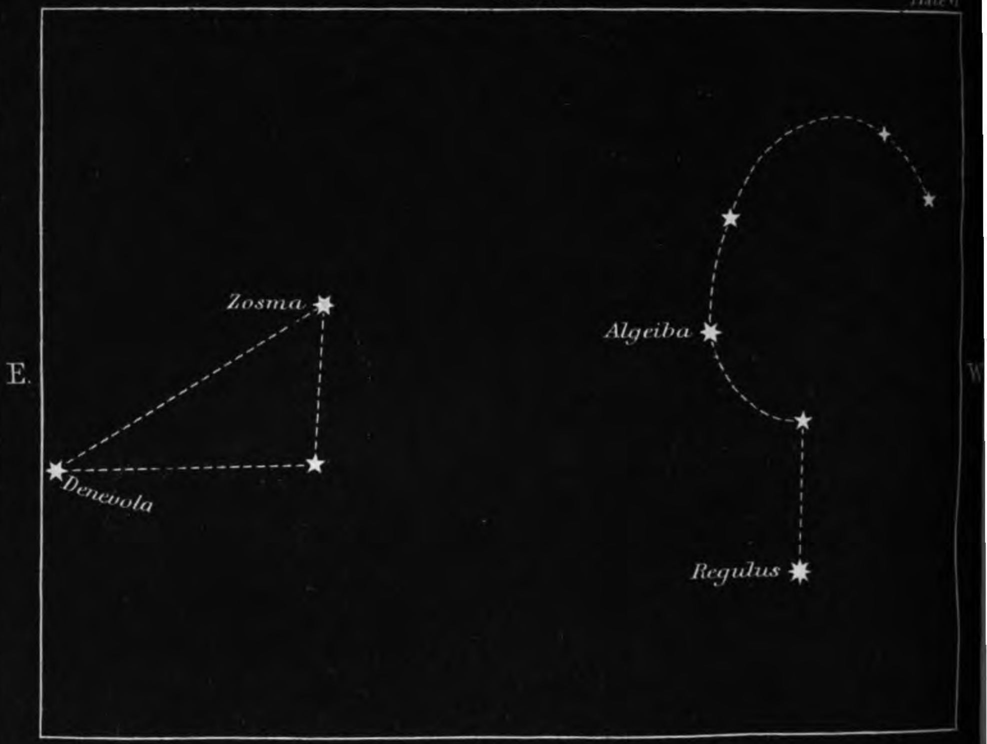
TO FACE PAGE 24



TO FACE PAGE 347

LEO

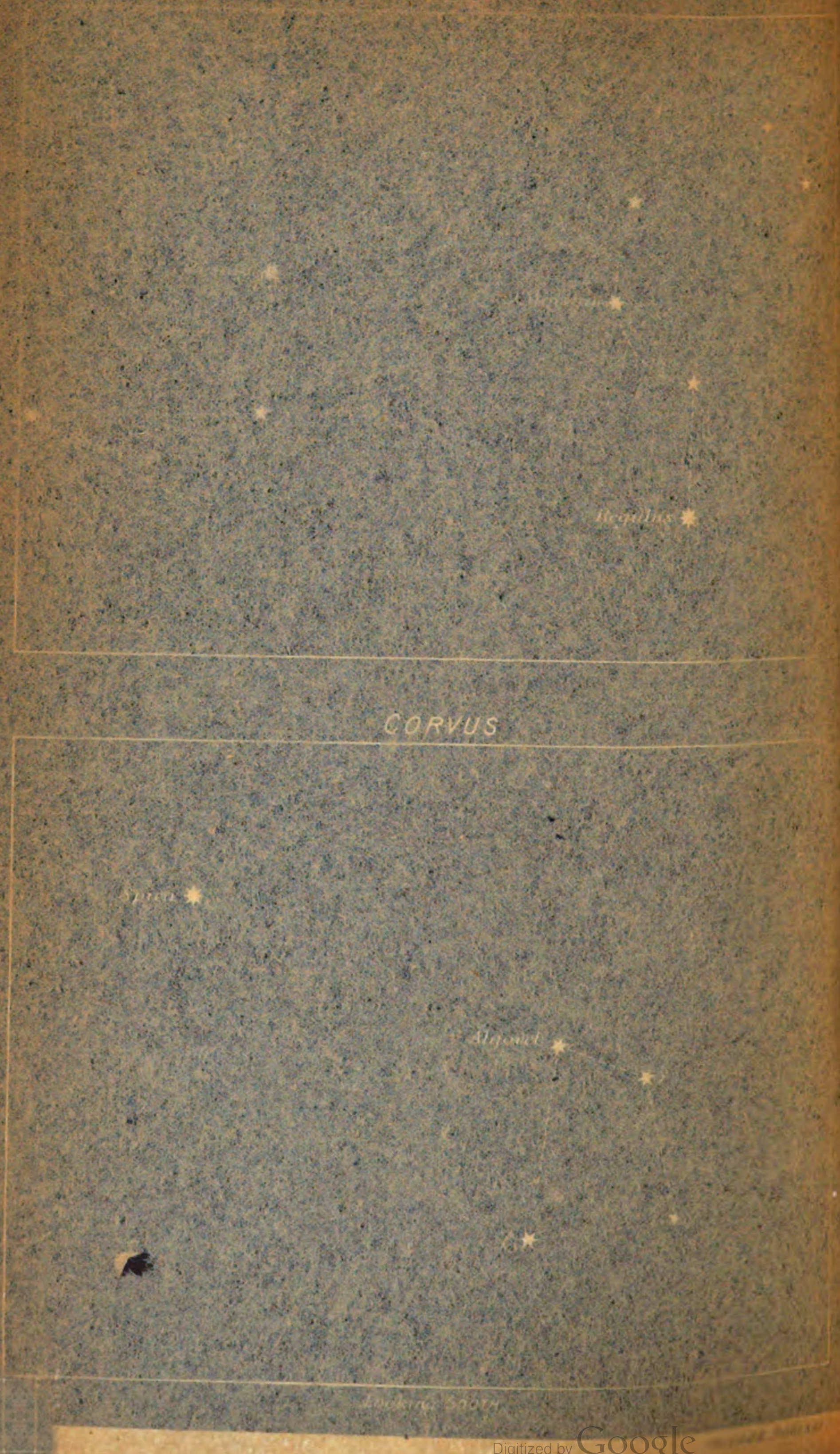
Plate VI



CORVUS

Plate VII

Looking SOUTH


Regulus
CORVUS
Spica
Algorab
Looking South

SQUARE OF PEGASUS.—Though sufficiently noticeable when looked for, is not altogether true in shape, none of the sides being of equal length.

A line from *Polaris* a little outside *Caph* (β Cassiopeiæ) will find it. The 'Plough' and the 'Square' are on the meridian about the same time, the one below and the other above the Pole. The stars marking the corners are *Alpheratz* in the N.E., *Algenib* in the S.E., *Markab* in the S.W., and *Scheat* in the N.W. **The Pointers of Pegasus.**

A line from *Markab* through *Scheat* points nearly to *Polaris:* these, therefore, are the 'Pointers of Pegasus.'

ORION.—Taken all in all, this is the finest combination of celebrities in the heavens. It is absolutely unmistakable, not only from its own brilliancy and form, but on account of its splendid surroundings. Orion, who was a mighty hunter in olden times, may justly be said to move in the highest stellar society.

As usual, however, the Giant is not at home in his celestial abode, but a quadrilateral figure is formed by *Betelguese* in the N.E., *Bellatrix* in the N.W., *Rigel* in the S.W., and κ in the S.E. corner. It is a thousand pities that κ is not at least as bright as its diagonal vis-à-vis *Bellatrix*, but Providence has willed otherwise.

In the centre of these four are three of the 2nd mag. lying nestled together, and very nearly in a straight line. They point N.W. and S.E., and—*mirabile dictu*—are spoken of as 'Orion's Belt.' Lying as it does on both sides of the Equator, and having so many finger-posts, Orion is a particularly useful constellation for star-finding in either hemisphere. **Orion's 'belt**

THE LION (*Leo*) requires the aid of a powerful imagination to be recognised as such. But though a singularly poor specimen of that king of animals, six of the stars bear a marked resemblance to a sickle or reaping hook, *Regulus*, of the 1st mag., being at the extremity of the handle. It is remarkable as the point in the sky from which the November meteor showers seem to radiate. **The 'Sickle.**

A line through *Phecda* and *Megrez*, away from the Pole, will pass through the 'sickle.'

THE CROW (*Corvus*) would require a 'chappie' to be 'three sheets in the wind' before he could see a bird, black or white. A much better crow could probably be made with the agricultural implement vulgarly termed a spade. A seaman, however, would have no difficulty in finding this constellation if described as a 'Cutter's mainsail,' and for the purpose of this chapter, a 'Cutter's mainsail' it shall be. *β Corvi* is at the clew, and *δ* is at the peak. The gaff points to the brilliant *Spica*, within easy hail.

The Cutter's mainsail.

The Scorpion (*Scorpio*) needs no special mention. *Antares*—the principal star—is easily picked out. This group is useful in finding the two '*Kiffas*' to the north-westward. *Kiffa Austr.* lies about midway between *Acrab* and *Spica*.

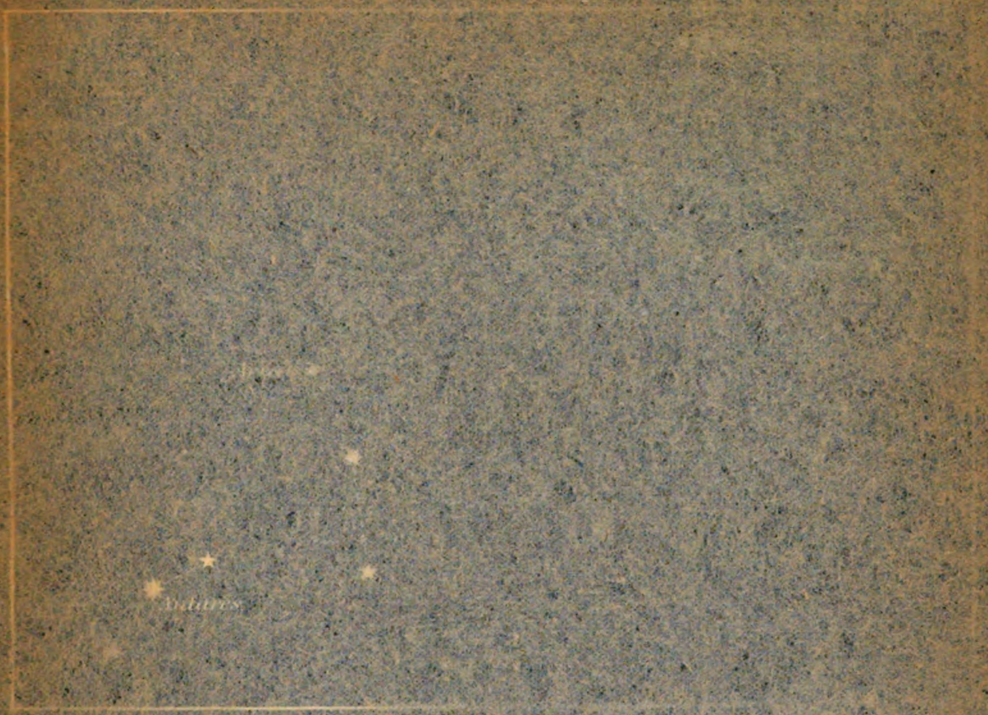
The Southern Cross (*Crux*), so far as its shape and brilliancy go, is rather a fraud. Still, there is sufficient of the cross about it to render it easy to find, especially as it is flanked by two stars of the 1st mag. pointing right at it.

To 'Cape Horners' it is a circumpolar group, and at its lower culmination is of course seen upside down, a phase of position which still further detracts from its merits and dignity as a cross. Nevertheless, romantic young ladies love to gaze at it whilst the waters ripple by the side of the ship. The effect is enhanced if a good looking officer should happen to be close by to explain matters celestial.

Vide pictorial explanation.

In the following description of how to find the stars, it will be noticed that in each case—when possible—*several* modes are given. This might seem superfluous, but it is really not so. For example, if an attempt were made to find a certain star when only 12° or 15° above either horizon, it might happen—and probably *would* happen—that some of the directing marks had either already set (if to the westward), or had not yet risen (if to the eastward): or a part of the sky might be clouded. The others would then come in handy; but in any case, by multiplying directions, the process of becoming acquainted with the stars is materially expedited. One star will be found to prove a key to another, that one to the next, and so on until the learner is on terms of intimacy with all that are worth knowing.

SCHEDAR (α Cassiopeiæ). Viewing this constellation as a chair, *Schedar*—its principal star—is at the bottom of the back leg. But such people as are not preternaturally gifted will probably fail to discover a chair-leg, back or front: so, taking it as a W, *Schedar* is at the foot of the right-hand portion of the letter. *Caph* (β) is at the top of the same part, and γ at the top of the centre portion.



SOUTHERN CROS

ITS MYST

TO FACE PA

better crow could probably be made with the agricultural implement vulgarly termed a spade. A seaman, however, would have no difficulty in finding this constellation if described as a 'Cutter's mainsail,' and for the purpose of this chapter, a 'Cutter's mainsail' it shall be. β *Corvi* is at the clew, and δ is at the peak. The gaff points to the brilliant *Spica*, within easy hail.

The Cutter's mainsail.

THE SCORPION (*Scorpio*) needs no special mention. *Antares*—the principal star—is easily picked out. This group is useful in finding the two '*Kiffas*' to the north-westward. *Kiffa Austr.* lies about midway between *Acrab* and *Spica*.

THE SOUTHERN CROSS (*Crux*), so far as its shape and brilliancy go, is rather a fraud. Still, there is sufficient of the cross about it to render it easy to find, especially as it is flanked by two stars of the 1st mag. pointing right at it.

To 'Cape Horners' it is a circumpolar group, and at its lower culmination is of course seen upside down, a phase of position which still further detracts from its merits and dignity as a cross. Nevertheless, romantic young ladies love to gaze at it whilst the waters ripple by the side of the ship. The effect is enhanced if a good looking officer should happen to be close by to explain matters celestial.

Vide pictorial explanation.

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SCORPIO WITH LIBRA

Plate VIII

SOUTHERN CROSS WITH CENTAURS

Plate IX

STAR GAZING IN THE TROPICS AND ITS MYSTERIOUS INFLUENCE.

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A line from *Alioth* (ϵ)—the third star in the handle of the 'Plough'—through *Polaris*, leads dead straight to the middle star (γ) in the W.

The parallax of *Caph* is 0″·154, equal to a distance of 124 billions of miles, or a light journey of 21 years.

When CASSIOPEIA is on the meridian *below* the pole, it resembles a straggling W, and when on the meridian *above* the pole, a very indifferent M.

CAPELLA (α **Aurigæ**).

Availing ourselves of the kindly services of the omni-present "Plough," a line from *Megrez* through *Dubhe* will pass between *Capella* and *Menkalinan* (β). *Capella* is 49¼° from *Dubhe*. Perhaps the easiest way to find it is by a line from *Caph* (β Cassiopeiæ) through γ Cassiopeiæ, and at a distance from the latter of 39½° will be found *Capella*, the second in command of the Northern Hosts. *Vega*, however, makes a good 'under-study,' and would be ready to step into the place of *Capella* should that mighty luminary be snuffed out.

A line at 30¾° from *Aldebaran* in the direction of the handle of the 'Plough' cannot fail to point out *Capella*; or a line from *Regulus* carried 5° or 6° eastward of *Castor* will do the same.

Sirius, *Betelguese*, *Nath*, and *Capella* are, to the eye, all four roughly equidistant; the connecting line is so slightly curved as almost to pass muster as straight. The droop of the curve is towards *Aldebaran*, which, with *Betelguese* and *Nath*, forms nearly an equilateral triangle. The opposite or hollow side of the curve faces the "Twins."

Capella and *Rigel* culminate within half a minute of each other.

Spectroscopic analysis gives every indication of an almost perfect constitutional similarity between our Sun and *Capella*. The actual diameter of *Capella* is about 18 times that of the Sun, and if the latter were placed at the same distance as *Capella* it would shine only as a star of the 6th mag. *Capella* is receding from us.

MENKALINAN (β **Aurigæ**).

Menkalinan lies 7½° to the eastward of *Capella* in the direction of *Castor* and *Pollux*. Being so close to its chief, *Menkalinan* is easily spotted.

ALMACH (γ **Andromedæ**)

Andromeda and Pegasus adjoin each other; in fact *Alpheratz*, the principal star in Andromeda, forms the N.E. corner of the 'Square of Pegasus.' *Scheat* (β Pegasi) stands at the N.W. corner of the 'Square,' and if we make this the starting point, and—drawing a line through *Alpheratz*—continue it in a curve to the N.E. with the hollow side towards the pole, the line will pass first through *Mirach-Mizar* (β), next through *Almach* (γ), and terminate in *Mirfack* (α Persei). The five stars enumerated above are roughly equidistant.

About 9° or so to the southward of *Mirfack*, and about 12° to the eastward of *Almach*, lies the famous variable star *Algol* (β Persei), known as the "Demon Star." These three form nearly a right-angled triangle, with *Algol* at the right angle.

The seven stars α Persei; α, β, γ, Andromedæ; and α, β, γ Pegasi; form a very remarkable group: once recognized they will serve to identify several others, including *Capella* and the 'Pleiades.'

Algeiba is the second star in the 'Sickle' from *Regulus.* Quite close to, on its southern side, is a star of the 6th mag. plainly visible with the binoculars.

ARCTURUS (α Boötis).

Arcturus—a regular 'scorcher'—is easily found from the 'Plough' by following the curve of the handle to a distance of 30½° from *Benetnasch.* Of course the student knows already that *Benetnasch* is the star at the extremity of the handle of the 'Plough,' just as *Regulus* is the star at the extremity of the handle of the 'Sickle.' 'Plough' and 'Sickle' naturally run together in one's mind.

Arcturus is slightly reddish in hue, and unmistakable as the brightest star in the northern heavens. In this respect it is hard pressed by *Capella* and *Vega;* whilst to the southward of the 'line' it is surpassed by *Sirius, Canopus,* and α *Centauri.* So far no really reliable value has been assigned to its parallax. This, coupled with its great lustre, points to extreme remoteness, and to its being probably the most stupendous of all the suns within our ken.

In composition *Arcturus* very much resembles our own sun, though there are points of difference. Taking the ascertained parallax of 0″·016, *Arcturus* is about 100 times greater in diameter than our sun, which means that it would just about fill the space between this earth and its primary!!! *Arcturus* is an approaching star. "*Prepare for ramming.*"

VEGA (α Lyræ).

Vega contests for supremacy with *Capella.* It is a toss up between them. A line from *Dubhe* a little outside the 'Guards,' and through a smaller edition of the 'Cutter's mainsail' (part of Draco), leads to this magnificent bluish-white star.

Also, a line from *Regulus,* nearly midway between *Arcturus* and *Benetnasch,* will strike it. Neither of these lines are specially good in themselves, but they cannot fail to discover such a 'blazer' as *Vega.*

A line from the tack of the real 'Cutter's mainsail' (Corvus), through *Spica,* and a long way beyond (87¾°), will fetch *Vega.* Also, a line from *Castor,* carried 51½° beyond *Polaris,* will lead sufficiently near for identification. *Vega, Arcturus,* and *Polaris,* form a large right-angled triangle, with *Vega* at the right angle.

Taken with neighbouring faint stars, *Vega* forms a small V, and occupies the extremity of one arm: the other extremity is marked by a pair of faint stars lying side by side: a binocular is mostly required to separate them; but with a good telescope and a steady support, *each* of these two is seen to be a close 'Double.' *Vega* itself has a faint companion, regarded as a good test for small astronomical telescopes.

The apex or bottom of the V is likewise composed of a pair of faint stars. The common saying that there are "wheels within wheels" is nowhere so well illustrated as in the starry firmament.

ARIDED or **DENEB** (α Cygni).

Arided is the principal member in a large fairly symmetrical cross. It stands at the head, and may be found in several ways.

A line from *Phecda* in the 'Plough,' carried through the outer 'Guard,' will nearly strike it: so also will a line from *Mirfack*, between β and γ of Cassiopeia. *Arided* and the three transverse stars (γ, δ, ϵ) are the most noticeable in the cross, and brighter than *Albireo* in the foot; this latter lies about the middle, and a few degrees north-eastward of a line joining *Vega* and *Altair*. In fact *Vega*, *Cygnus*, and *Altair* are neighbours. *Arided* is 23¾° from *Vega*.

A line from *Alphacca* in the 'Crown,' passing a little north-eastward of *Vega*, will reach the centre star (γ).

Arided must be an indefinitely remote star, as efforts to determine its parallax have quite failed. Though it stands at the bottom of the list of the ten brightest stars north of the equator, it is a "giant sun."

Polaris, *Capella*, and *Arided* form almost an exact isosceles triangle. When, roughly speaking, *Capella* has about the same altitude west that *Arided* has east, the isosceles triangle will be most apparent. About midway between the two, and lying under *Polaris*, will be seen Cassiopeia's "Chair," if the observer be north of 50°.

ALTAIR (*α* Aquilæ)

Altair lies between two much fainter stars in the same line. The three point almost fair to *Vega*. A line from *Polaris* through γ, the centre star of Cygnus, passes a little to the eastward of *Altair*. Also a long line from *Phecda* in the body of the 'Plough,' passing through *Vega*, and carried beyond it for 34½°, will strike *Altair*.

A line from *Alpheratz* through *Scheat* will pass fairly close to *Altair* at 49½° from *Scheat*; but a line from *Algenib* through *Markab* will lead straight to it, passing on the way about 5° to the northward of *Enif* (ϵ Pegasi). The three transverse stars in the cross of Cygnus (δ, γ, ϵ) point nearly to *Enif*.

A line from γ through β Cassiopeiæ leads to *Altair*, but taken in the opposite direction leads to *Capella*. All four, therefore, form a very long line, with Cassiopeia as half-way house.

Finally, a line from *Vega* through β, in the foot of Cygnus, will pass close to *Altair*. It is one of the stars that are approaching this earth.

REGULUS (*α* Leonis).

Regulus is at the extremity of the handle of the 'Sickle.' A line from *Bellatrix* through *Betelguese* leads straight to it at a distance from the latter of 62½°. Or a line from *Aldebaran* passing midway between *Pollux* and *Procyon* will do the same.

This star shews a well marked motion of recession. The 'Sickle' is remarkable as containing the point from which the periodic November meteors seem to radiate.

ALDEBARAN (*α* Tauri).

At about the same distance (23°) from the middle star of Orion's 'Belt' as *Sirius*, but in the opposite direction, is 'ruddy *Aldebaran*.' Its actual colour is pale rose. A line 15¾° in length, extending from *Bellatrix* to the 'Pleiades,' just shaves *Aldebaran* in passing. Like *Vega*, it is a star in the foot of a small and faint letter, but in this instance the resemblance is more to the letter A. It is an aid to memory to associate A with *Aldebaran* and V with *Vega*.

ALDEBARAN (a Tauri).

Aldebaran is accepted by some as a standard for stars of the 1st mag.; so also is *Altair*. By magnitude is meant brightness or lustre, and not actual size of the body itself; for example, *Sirius*, owing to its nearness and stage of its existence, outshines stars known to be infinitely larger.

By instrumental measurement of *Aldebaran* and *Altair*, each is found to give exactly three times as much light as the "Pole star." In the same photometric scale the magnitude of *Arcturus* is expressed as 0·0, and *Sirius* as − 1·4. The latter gives nine times more light than *Aldebaran*.

Stellar photometric values are not yet quite on a satisfactory footing, as so much depends upon details of observation. *Aldebaran* is receding from us at the rate of 30 miles a second.

PROCYON (a Canis Minoris).

Procyon is easily found. It is a brilliant star, though no doubt loses by comparison with *Sirius*. These two and *Betelguese* form a conspicuous equilateral triangle, whose sides have a mean measurement of 26½°. *Regulus*, *Alphard*, and *Procyon* form a right-angled triangle, in which *Alphard* occupies the right angle, and lies to the southward of the other two.

Procyon is receding at the rate of 27 miles per second. This is slow compared with some. Velocities of 100 miles a second are not unknown.

SIRIUS (a Canis Majoris).

Sirius, the 'Dog-star,' has poetically been termed the 'Monarch of the Skies,' being far and away the brightest of all the stars. In certain weathers it sparkles with the colours of the diamond, though its actual colour is white with a bluish tinge. The three stars in Orion's 'Belt' point nearly to it. To find it no other assistance is required, scarcely even this much.

The mass of *Sirius* is about 2¼ times that of our sun. It has a companion about the same size as the latter, but at present the two stars are so close that no telescope will divide them. The companion is of the 10th mag., and was discovered by Alvan Clark in 1862. The period of revolution of *Sirius* and its companion is, according to Gore, about 58½ years.

Sirius emits about 40 times more light than our sun.

CASTOR and POLLUX (a and β Gemini).

Castor and *Pollux* lie only 4½° apart. *Pollux* (β) is the more southern of the two, and slightly the brighter. A line from *Mirfack* through *Capella* leads straight to *Pollux*. Also, a line from *Rigel* through the middle star of the 'Belt,' and thence onward through γ Geminorum, will conduct to the 'Twins.' γ Geminorum is a *Naut. Alm.* star of mag. 2·0, and lies nearly midway between *Betelguese* and *Pollux*. So far, astronomers have not been able to assign it any parallax. It may therefore be regarded as immeasurable in distance It is named *Alhena*.

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Pollux, *Castor*, *Menkalinan*, and *Capella*, form a long flat curve, with a gap between *Castor* and *Menkalinan* big enough for two more stars to complete. *Pollux* is one of the bright stars of the northern hemisphere, but near the 'bottom of the class.'

Castor (a) is a very fine specimen of a binary star; that is to say, it has a companion (3rd mag.), and the two revolve round each other in a period of about 1,000 years. A good ship's telescope will separate them.

Mizar, *Alioth*, *Megrez*, and *Merak* (four stars of the 'Plough,' all nearly in a line) point to *Castor* at 43° from *Merak*. *Merak*, *Castor*, and *Capella*, form a right-angled triangle, the right angle being at *Castor*.

Castor and *Pollux* lie about midway between the square of the 'Plough' and the square of Orion. They run nearly parallel to the 'Pointers,' and are separated from each other by only 1° less than the 'Pointers.'

Castor, *Procyon*, and *Pollux* pass the meridian in this order at intervals of five or six minutes.

SPICA (*α* Virginis)

A line from *Polaris* through *Arcturus* leads a little eastward of *Spica*. It has already been stated that *Arcturus* is easily found by following the curve of the handle of the 'Plough'; well, by continuing this curve for 32¾° beyond *Arcturus*, you come to *Spica*. To the eye, therefore, it is roughly about as far from *Arcturus* as the latter is from *Benetnasch*.

Spica, *Denebola*, and *Arcturus* form very nearly an equilateral triangle. The sides are

Spica	35°	*Denebola*.
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The gaff of the 'Cutter's mainsail' (Corvus) points dead straight at *Spica*, which is 14⅓° from *Algoreb*, the star in the peak. *Spica* is approaching us.

ALPHACCA (*α* Coronæ.)

Alphacca, though not in itself very bright, is conspicuous among six faint stars forming a segment of a circle, which, by a little stretch of the imagination, might be taken to bear some resemblance to a crown; this constellation is accordingly termed the "Northern Crown."

A line from *Alphard* carried 19½° beyond *Arcturus* leads to *Alphacca*; or a line from *Dubhe* carried through between the three stars forming the handle of the 'Plough' cuts it in another direction. The distance of *Alphacca* appears to be immeasurable.

ALPHARD (*α* Hydræ).

Regulus, *Alphard*, *Procyon*, and *Pollux* would form a decent oblong were it not that the last named prefers the companionship of his brother. A line from *Algeiba* (the 3rd star in the 'Sickle') through *Regulus* (the 1st star in the 'Sickle') points nearly to *Alphard* at 23° from *Regulus*.

A long line from *Arcturus* to *Sirius* picks up *Alphard* on the way. A line from *Rigel* through *κ* Orionis passes near it.

Alphard, *Procyon*, *γ* Geminorum, and *Nath* are all in a straight line, having an easterly and westerly bearing. *Regulus*, *Alphard*, and *Procyon* form a right-angled triangle, the right angle being at *Alphard*.

Alphard might appropriately be dubbed the 'Lone Star,' as it is the only one of the 2nd mag. in an area of about 40° square. In Arabic, *Alphard* means "The solitary one."

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Pollux, *Castor*, *Menkalinan*, and *Capella*, form a long flat curve, with a gap between *Castor* and *Menkalinan* big enough for two more stars to complete. *Pollux* is one of the bright stars of the northern hemisphere, but near the 'bottom of the class.'

Castor (α) is a very fine specimen of a binary star; that is to say, it has a companion (3rd mag.), and the two revolve round each other in a period of about 1,000 years. A good ship's telescope will separate them.

Mizar, *Alioth*, *Megrez*, and *Merak* (four stars of the 'Plough,' all nearly in a line) point to *Castor* at 43° from *Merak*. *Merak*, *Castor*, and *Capella*, form a right-angled triangle, the right angle being at *Castor*.

Castor and *Pollux* lie about midway between the square of the 'Plough' and the square of Orion. They run nearly parallel to the 'Pointers,' and are separated from each other by only 1° less than the 'Pointers.'

Castor, *Procyon*, and *Pollux* pass the meridian in this order at intervals of five or six minutes.

SPICA
(α Virginis)

A line from *Polaris* through *Arcturus* leads a little eastward of *Spica*. It has already been stated that *Arcturus* is easily found by following the curve of the handle of the 'Plough'; well, by continuing this curve for 32¾° beyond *Arcturus*, you come to *Spica*. To the eye, therefore, it is roughly about as far from *Arcturus* as the latter is from *Benetnasch*.

Spica, *Denebola*, and *Arcturus* form very nearly an equilateral triangle. The sides are

Spica	35°	*Denebola*.
Denebola	35¼°	*Arcturus*.
Arcturus	32¾°	*Spica*.

The gaff of the 'Cutter's mainsail' (Corvus) points dead straight at *Spica*, which is 14½° from *Algoreb*, the star in the peak. *Spica* is approaching us.

ALPHACCA
(α Coronæ.)

Alphacca, though not in itself very bright, is conspicuous among six faint stars forming a segment of a circle, which, by a little stretch of the imagination, might be taken to bear some resemblance to a crown; this constellation is accordingly termed the "Northern Crown."

A line from *Alphard* carried 19½° beyond *Arcturus* leads to *Alphacca*; or a line from *Dubhe* carried through between the three stars forming the handle of the 'Plough' cuts it in another direction. The distance of *Alphacca* appears to be immeasurable.

ALPHARD
(α Hydræ).

Regulus, *Alphard*, *Procyon*, and *Pollux* would form a decent oblong were it not that the last named prefers the companionship of his brother. A line from *Algeiba* (the 3rd star in the 'Sickle') through *Regulus* (the 1st star in the 'Sickle') points nearly to *Alphard* at 23° from *Regulus*.

A long line from *Arcturus* to *Sirius* picks up *Alphard* on the way. A line from *Rigel* through κ Orionis passes near it.

Alphard, *Procyon*, γ Geminorum, and *Nath* are all in a straight line, having an easterly and westerly bearing. *Regulus*, *Alphard*, and *Procyon* form a right-angled triangle, the right angle being at *Alphard*.

Alphard might appropriately be dubbed the 'Lone Star,' as it is the only one of the 2nd mag. in an area of about 40° square. In Arabic, *Alphard* means "The solitary one."

NATH
(β Tauri)

This star and *Bellatrix* are on the meridian at the same time, and distant from each other 22¼°. It happens that this is also its exact distance from *Betelguese.*

A line from *Schedar* carried 31¼° beyond *Mirfack* will fetch *Nath:* all three are in a perfectly straight line. A line joining *Bellatrix* and *Polaris* will pass through *Nath*, and a little eastward of *Capella.*

ANTARES
(α Scorpii).

This is a red star, and, after the manner of *Altair*, lies between two fainter ones; but in this case the three are bow-shaped. The bow points to a larger one close by to the north-westward. Their respective lines of direction cross at a wide angle—probably about 70°.

It is important to notice well these two bows, because with their aid it is quite easy to find α and β Libræ. The larger bow is formed by *Acrab* (β Scorpii) to the northward, δ Scorpii in the middle, and π Scorpii to the southward.

Arcturus, *Spica*, and *Antares* form a right-angled triangle, with the right angle at *Spica.* A line from *Algeiba* through *Spica* will lead right to *Antares*, at 46° from *Spica.*

KIFFA BOREALIS
(β Libræ) &
KIFFA AUSTRALIS
(α Libræ).

Kiffa Borealis is barely 9¼° from *Kiffa Australis* (α Libræ). A line from *Regulus* through *Spica* leads to *Kiffa Australis*, at a distance from *Spica* of rather over 21¼°; but these two *Kiffas* can be better found thus:—A line from *Antares* carried north-westward through *Acrab* leads to *Kiffa Borealis* at about 16° from *Acrab.*

The gaff of the 'Cutter's mainsail,' extended a little south of *Spica*, cuts *Kiffa Borealis* in another direction.

A line from *Antares* carried 18° beyond the middle star of the large bow leads to *Kiffa Australis.*

RAS ALHAGUE
(α Ophiuchi).

Ras Alhague, with *Vega* and *Altair*, form an isosceles triangle, *Altair* being at the apex. The sides are

Altair	34¼°	*Vega.*
Altair	33½	*Ras Alhague.*
Vega	29½	*Ras Alhague.*

A line from *Arcturus* to *Altair* passes some 4° or 5° north of *Ras Alhague*, and a line from *Antares* to *Vega* will almost pass through it.

A line from *Polaris*, passing between *Etanin* (γ Draconis) and *Alwaid* (β Draconis), strikes *Ras Alhague* at about 39¼° from *Etanin*, and 39¾° from *Alwaid.* This is an excellent mark. *Etanin* and *Alwaid* (two Naut. Alm. stars) are half way between *Polaris* and *Ras Alhague:* they follow each other on the meridian at an interval of two minutes.

The three transverse stars of Cygnus point westward to *Etanin* and *Alwaid:* all five are pretty much in the same street. *Etanin* is just 14½° from *Vega.* β Draconis is also called *Rastaban.*

HAMEL (α Arietis).

A line from *Betelguese* in a north-westerly direction through *Aldebaran*, and at a distance from the latter of 35½°, will lead nearly to it. Also, it will be found half way on the line joining *Algenib* and the 'Pleiades.'

A line from *Scheat* through *Alpheratz*, at a distance of 27¼° from the latter, will pass a trifle northward of *Hamel*. It is therefore nearly double the distance from *Alpheratz* that *Alpheratz* is from *Scheat*.

Hamel, *Menkar*, and the 'Pleiades' form an equilateral triangle with sides of about 23°, *Menkar* being at the southern corner.

Hamel has a neighbour named *Sheratan* (β Arietis, mag. 2·8) lying about 4° to the southward and westward. At about 1½° to the southward of *Sheratan* is the faint star *Mesartim* (γ).

Sheratan and *Hamel* point straight to *Capella* at a distance of 44° from *Hamel*. The latter lies nearly due west of the 'Pleiades.'

MENKAR (α Ceti).

Menkar lies nearly in a straight line from β Andromedæ through *Hamel*, at a distance from the latter of 23½°. *Hamel* is about half way.

A line from *Sirius* through *Rigel* will lead to it at 35¼° from *Rigel*. So also will a line from *Procyon* through *Bellatrix*, with the latter as 'half-way house.'

Menkar lies between *Rigel* and *Algenib*, but nearer to Rigel. A line from *Capella*, through the 'Pleiades,' points nearly to it. *Menkar* must not be confounded with its younger brother (γ), which lies about 4¾° to the southward and westward.

DENEB KAITOS or **DIPHDA** (β Ceti).

A line from *Aldebaran* through *Menkar*, carried on for 40¾°, will lead to it. For stars belonging to the same constellation, *Menkar* and *Deneb-Kaitos* are rather widely separated.

A long line from *Arided* through *Markab* goes straight to it. A line from *Alpheratz* through *Algenib*, and extended 34°, goes near enough to indicate it.

ADARA (ε Canis Majoris).

Nearly 6° to the westward of *Sirius* is *Mirzam* (β Canis Maj.) A line from *Betelguese* midway between *Mirzam* and *Sirius* will strike *Adara* at 12¾° from *Sirius*.

Or, a line from *Betelguese* through *Sirius* takes straight to δ, about 3½° to the N.E. of *Adara*. δ and ε are therefore near neighbours.

FOMALHAUT (α Piscis Australis).

A line from *Scheat* through *Markab*, carried nearly due south for 44¾° from the latter, will strike it. The same line carried in the opposite direction leads to *Polaris*.

Fomalhaut, *Scheat*, and *Markab* pass the meridian within a few minutes of each other.

A very slightly curved line from *Aldebaran* through *Menkar*, and onward through *Deneb-Kaitos*, will lead to it at 26¾° from the latter. This is a long stretch, but serves its purpose well. The four stars are roughly equi-distant.

A line from *Vega* passing eastward of *Altair* will shew the position of *Fomalhaut* at 59° from *Altair*.

Though *Fomalhaut* is very nearly a star of the 1st mag., the light of *Sirius* exceeds it twelve times ; *ergo*, *Sirius* is "somebody."

CANOPUS (α Argûs).

Canopus ranks next to *Sirius* in brilliancy, and bears from it nearly S. 5° W., distant 36¼°. It is therefore easily found. From *Fomalhaut*, *Canopus* is distant 78½°, and about half as far from *Achernar*.

Up to now, Astronomers have failed to detect any reliable parallax in this brilliant star, and should further research confirm this, the light of *Canopus* must take at least 65 years to reach us—probably much longer. At a distance demanding a light journey of this duration, our own sun would only appear as a star of the 7th mag., and barely visible to the best unaided sight. *From this it is calculated that Canopus is brighter than 2500 suns like ours ! ! !*

It requires a pretty heavy purchase to hoist this in ; nevertheless, it is true so far as our present knowledge goes.

ACHERNAR (α Eridani).

This star and β Centauri are almost exactly on opposite sides of the south pole, so come to the meridian near about the same time, one above, and the other below it. Bearing this in mind, and as β Centauri is quite unmistakable, there can be no difficulty in finding *Achernar*. It is 62¼° from β Centauri, with the Pole half-way between them.

Achernar lies 40° eastward of α Pavonis, and, for finding purposes, has practically the same declination. It lies nearly on a line joining *Canopus* and *Fomalhaut*, and at an equal distance from both.

THE SOUTHERN TRIANGLE (α Trianguli Australis).

α in *The Southern Triangle* is the most southern star in the list, and lies nearly due south of *Antares* at a distance of 42¾°. It is 26½° from α Pavonis, and about the same from β Crucis (east side of "Southern Cross"). The east side of the "Cross" is that side which is next to the "Centaurs."

THE PEACOCK (α Pavonis).

A line from γ and β of the "Southern Cross" through α Tri. Austr. will indicate it. α Tri. Austr. is about midway between β Crucis and α Pavonis: its exact distance from the latter is 26° 23′.

THE CRANE (α Gruis).

The Crane is 18½° from α Pavonis in a N.E'ly direction ; and from *Fomalhaut* it bears S.S.W. ¼ W. 19¾°. It is therefore nearly midway between them. Its proximity to these two stars makes it easy to find.

From *Achernar* α Gruis is 32¾°.

THE PHŒNIX (α Phœnicis).

α in *The Phœnix* is 24½° to the southward of *Deneb-Kaitos*. It lies nearly midway between *Achernar* and *Fomalhaut*, though not in a straight line with them.

DENEBOLA (β Leonis).

A line from *Procyon* through *Regulus* leads straight to *Denebola* at a distance of nearly 24¾° from the latter. If this line be carried on for 35¼°, it will pass a little to the southward of *Arcturus*. From these measurements it will be seen that *Denebola* lies rather better than half-way between *Arcturus* and *Regulus*.

To the eastward of the 'Sickle' are three stars in the form of a right-angled triangle; *Denebola* is the most eastern and brightest.

MIRFACK (α Persei).

A line from γ of the "Guards" through *Polaris* leads near *Mirfack*. Also, it can be cross-cut by a line from *Pollux* through *Capella*, at a distance of 19° from the latter.

A diagonal line from *Phecda* (γ), through the body of the 'Plough,' to *Dubhe* (α), points dead straight at *Mirfack*. Also, a line from γ Cassiop. through δ Cassiop. points nearly to *Mirfack*.

It is distinguished as the principal among a festoon of stars in this part of the heavens. Between 9° and 10° southward of *Mirfack* is the famous variable star *Algol* (β).

A line from *Menkalinan* through *Capella* points to *Algol*, and if continued will reach *Algenib*.

A line from *Markab* through *Alpheratz* leads fair to *Mirfack*. On the way it passes a few degrees north and westward of β and γ Andromedæ.

The star cluster in Perseus is well seen with a binocular.

ALPHERATZ (α Andromedæ).

Alpheratz stands at the N.E. corner of the 'Square of Pegasus.' β and γ Andromedæ and *Algol*, tailed on to the 'Square' at this corner, constitute a large edition of the 'Plough,' with *Scheat* and *Markab* as 'Pointers.'

A line from γ to α Cassiop. (*Schedar*), will pass through the middle of the 'Square.'

A line from *Polaris* passing through *Caph* (β Cassiop.) will point out *Alpheratz* at 30° due south from *Caph*. The two last named pass the meridian within a few seconds of each other.

Polaris, *Caph*, *Alpheratz*, and *Algenib* are all nearly in a row.

A line from *Caph* through *Schedar* points straight to *Almach* (γ Andromedæ).

α Persei, γ, β, and α Andromedæ lie in a curve and roughly equi-distant. The hollow side of the curve is towards Cassiopeia's 'Chair.'

ALGENIB (γ Pegasi).

Algenib marks the S.E. corner of the 'Square.' A line from *Capella* through *Mirfack* will lead to it.

A line from *Vega* through the middle star (γ) in the Cross of Cygnus leads through η Pegasi straight to *Scheat*, and thence diagonally across the 'Square' to *Algenib*.

MARKAB (α Pegasi).

Markab indicates the S.W. corner of the 'Square.' A line from it through *Scheat* at the N.W. corner leads to *Polaris*. Therefore, these two may appropriately be described as the 'Pointers of Pegasus.' They pass the meridian within a minute of each other.

A line from *Polaris* carried a shade outside (westward) of *Caph* (β Cassiop.) will pass through the centre of the 'Square.'

SCHEAT (β Pegasi).

Scheat is not given in the *Naut. Alm.* for 1895. This corner (N.W.) of the 'Square' is well marked by two neighbouring stars, distance about 5°, forming with *Scheat* a small triangle.

The 'Square of Pegasus' is a good sky mark for a large number of stars both far and near.

PHACT (α Columbæ)

A little westward of a line from *Aldebaran*, through *Rigel*, at a distance of 26½° from the latter, is *Phact*. Or it may be found by a line from *Betelguese* through κ Orionis at a distance of 24½°.

Phact and κ Orionis pass the meridian with an interval between them of seven minutes. *Phact* comes first. It is on a line between *Rigel* and *Canopus*.

CENTAUR No. 2. (β Centauri).

Centaur No. 2. cannot be mistaken, being the nearer of the two to the 'Southern Cross.' Its neighbour (α Centauri) is nearest to earth of all the fixed stars, and the determination of its parallax is supposed to be the best yet made.

α Centauri is a double star, that is to say, it is one which, with the aid of the telescope, can be separated into two. Such stellar pairs as are known to be in orbital movement, or revolving round their common centre of gravity, are termed "Binary Stars." α Centauri belongs to this class. The period of revolution of the two components is computed to be 86 years, and their mean angular distance apart as seen from this earth is 18″. Any one not versed in such matters might wonder how two immense bodies could move round each other without danger of collision, but wonder will cease when it is understood that 18″ in their case represents a distance apart of (in round numbers) one thousand million miles, or about eleven times the distance between the earth and sun.

Seeing that we are now acquainted with many thousands of such binary systems, we may reasonably infer that the stars are suns forming the centres of planetary systems similar to our own, but which, from their great distance, are invisible. For instance, if such a giant as Jupiter were to move round α Centauri at the same distance from that star as it is from our sun, not even the great Lick telescope would enable us to see it.

Though, as just stated, α Centauri is the nearest known star, the distance of β Centauri is immeasurable ; so here we have a case of two neighbouring stars in the same constellation, and of nearly equal brightness, separated in space by a gulf of inconceivable vastness.

α Centauri and its companion emit about 2½ times the light of the sun.

Annual Parallax.

With regard to the parallax of the stars : of late years there have been many workers in this field of research, but the quantities are so extremely minute, and in this connection so very little means so very much, that except in a limited number of cases the distances arrived at can only be accepted as the very roughest approximations.

Suffice it to say that, to the extent of a few billions, more or less, Astronomers are pretty well agreed as to some of the nearer stars. None have yet been discovered with a parallax amounting to even a single second (1") of arc, which proves that no star exists within 20 billions of miles of the earth. Try and realise 20 billions. It means *20 millions of millions ! !*

The undermentioned are a few of the best known nearest stars :—

Star distances.

	Magnitude.	Parallax.	Light years.	Miles.
α Centauri	+ 0·7	+ 0″·750	4·3	25 billions.
61 Cygni	+ 5·1	+ 0 ·433	7·5	44 „
Sirius	− 1·4	+ 0 ·388	8·4	49 „
Procyon	+ 0·5	+ 0 ·341	9·6	56 „

Let it be understood that brightness or magnitude cannot be considered a test of distance, stars like *Arcturus*, *Betelguese*, *Canopus*, and *Arided* being infinitely further off than some fainter ones like 61 Cygni (mag. 5·1) α Draconis (mag. 3·6), &c.

For further confirmation, take α Centauri and *Arcturus*, which have practically much the same magnitude ; light from the first named requires 4¼ years to reach us, as compared with some 200 years or so from the other.

Altair and *Aldebaran* are closely comparable in magnitude, yet *Aldebaran* is more than double the distance from us.

Polaris has a light journey of 42 years, but its near neighbour *Kochab* (β Urs. Min.), with but slightly less brilliancy, has a light journey of 148 years.

Take *Sirius* and *Canopus ;* one 8½ years, the other 109 years. Cases might be multiplied.

At present, stars of the 18th magnitude constitute the seeing limit of the very biggest telescopes. It is calculated that light from *some* of the 17th mag. stars takes probably 30,000 years to reach us ! ! !

Revelations such as these give one some faint idea of the sublimity of the Universe, and of the completely insignificant part played by this our earth in its composition.

ALDERAMIN (α *Cephei*) and **ALPHIRK** (β *Cephei*)

A regular and moderate curve from *Arided* (α Cygni) to *Polaris* will pass first through *Alderamin* and next through *Alphirk.* The convex side of the curve is towards Cassiopeia's Chair. These two stars are about 8° apart, and of the respective magnitudes of 2·6 and 3·4. A line from *Schedar* through *Caph* points straight to *Alderamin.*

Star magnitudes.

NOTE.—With regard to magnitudes, it is obvious that some star must be selected as a *standard.* The adopted unit of brightness is that of *Aldebaran*, which is accordingly designated 1·0, and the remainder are valued by photometric comparison. The mags. of the seven stars brighter than *Aldebaran* are indicated by figures less than 1·0 :—thus the value 0·0 for *Arcturus* indicates that star to be one mag. brighter than *Aldebaran ;* and the value *minus* 1·4 for *Sirius* makes it 2·4 mags. brighter than *Aldebaran.*

To get at a star's distance in "Light-years" the formula is $D_y = \frac{3 \cdot 262}{p''}$, p'' being parallax. A star's distance in *miles* is determined from the equation.

$$D_m = \frac{206265 \times R}{p''},\ R \text{ being sun's distance.}$$

Astronomers now look hopefully to photography to supply more reliable measures of stellar parallax ; so it is hardly worth while altering those given herein till something really definite has been arrived at.

USEFUL NAVIGATIONAL STARS—EPOCH, 1895.

(In order of Right Ascension).

Photometric Mags.	NAMES.	Right Ascension.	Declination.	Parallax.	Distance in Light Years.	Distance in Billions of Miles.
		H. M.	°	"		
2·1	Alpheratz (*a Andromedæ*) ...	0 3	28·5 N.	0·059	55	324
3·0	Algenib (*γ Pegasi*) ...	0 8	14·6 N.			
2·4	*——— (*a Phœnicis*)	0 21	42·9 S.			
2·2 to 2·8	*Schedar (*a Cassiopeiæ*) ...	0 35	56·0 N.	·036	91	532
2·1	Deneb-Kaitos (*β Ceti*) ...	0 38	18·6 S.			
1·0	*Achernar (*a Eridani*) ...	1 34	57·8 S.			
2·1	Almach (*γ Andromedæ*) ...	1 57	41·8 N.			
2·0	Hamel (*a Arietis*) ...	2 1	23·0 N.	·079	41	242
2·7	Menkar (*a Ceti*)	2 57	3·7 N.			
1·9	*Mirfack (*a Persei*) ...	3 17	49·5 N.	·087	37	220
1·0	Aldebaran (*a Tauri*)	4 30	16·3 N.	·101	32	189
0·2	*Capella (*a Aurigæ*) ...	5 9	45·9 N.	·095	34	202
0·3	Rigel (*β Orionis*)	5 10	8·3 S.	·040	81	478
1·9	Nath (*β Tauri*)	5 20	28·5 N.	·063	52	304
1·8	Alnilam (*ε Orionis*)	5 31	1·3 S.			
2·7	*Phact (*a Columbæ*) ...	5 36	34·1 S.			
1·0 to 1·4	Betelguese (*a Orionis*) ...	5 50	7·4 N.	·022	148	870
2·1	Menkalinan (*β Aurigæ*) ...	5 52	45·0 N.	·062	53	309
0·4	*Canopus (*a Argûs*)	6 22	52·6 S.			
– 1·4	Sirius (*a Canis Majoris*) ...	6 41	16·6 S.	·388	8	49
1·5	Adara (*ε Canis Majoris*) ...	6 55	28·8 S.			
1·6	*Castor (*a² Geminorum*) ...	7 28	32·1 N.	·198	16	97
0·5	Procyon (*a Canis Minoris*) ...	7 34	5·5 N.	·341	10	56
1·1	Pollux (*β Geminorum*) ...	7 39	28·3 N.	·057	57	336
2·5	*Tureis (*ι Argûs*)	9 14	58·8 S.			
2·0	Alphard (*a Hydræ*) ...	9 22	8·2 S.			
1·4	Regulus (*a Leonis*)	10 3	12·5 N.	·089	37	215
2·5	Algeiba (*γ¹ Leonis*) ...	10 14	20·4 N.			
2·0	*Dubhe (*a Ursæ Majoris*) ...	10 57	62·3 N.	·046	71	416
2·2	Denebola (*β Leonis*) ...	11 44	15·2 N.	·029	112	660
1·3	*——— (*a¹ Crucis*)	12 21	62·5 S.			
1·2	Spica (*a Virginis*) ...	13 20	10·6 S.			
2·0	*Benetnasch (*η Ursæ Majoris*) ...	13 43	49·8 N.	Imme	asura	ble
1·2	*——— (*β Centauri*) ...	13 56	59·9 S.	Imme	asura	ble
0·0	Arcturus (*a Boötis*)	14 11	19·7 N.	·016	204	1196
2·1	*Kochab (*β Ursæ Minoris*)	14 51	74·6 N.	·022	148	870
2·7	Kiffa-Borealis (*β Libræ*) ...	15 11	9·0 S.			
2·4	Alphacca or Gemma (*a Coronæ*)	15 30	27·1 N.	Imme	asura	ble
2·9	Acrab (*β¹ Scorpii*)	15 59	19·5 S.			
1·1	Antares (*a Scorpii*) ...	16 23	26·2 S.			
2·2	*———(*a Trianguli Australis*)	16 38	68·8 S.			
2·2	Ras Alhague (*a Ophiuchi*) ...	17 30	12·6 N.			
0·2	*Vega (*a Lyræ*)	18 33	38·7 N.	·092	35	208
1·0	Altair (*a Aquilæ*)	19 46	8·6 N.	·214	15	89
2·1	*——— (*a Pavonis*) ...	20 17	57·1 S.			
1·5	*Arided or Deneb (*a Cygni*) ...	20 38	44·9 N.	Imme	asura	ble
2·4	Enif (*ε Pegasi*)	21 39	9·5 N.			
1·9	*——— (*a Gruis*)	22 2	47·5 S.			
1·3	*Fomalhaut (*a Piscis Australis*)	22 52	30·2 S.			
2·6	Markab (*a Pegasi*) ...	23 00	14·6 N.	·081	40	236

Note.—The stars prefixed by * are specially mentioned in B of Lecky's A B C Tables: with two exceptions, the declinations of the remainder come within the limits of upper portion of the same Table. Menkalinan having approximately the same declination as Arided, the tabular values will do for either ; so the only one not provided for is Almach.

Where two mags. are given, the star is variable.

FIFTY USEFUL NAVIGATIONAL STARS—EPOCH 1895.

(In order of Declination.)

NORTHERN HEMISPHERE.	°	SOUTHERN HEMISPHERE.	°
Kochab	74·6 N.	Alnilam	1·3 S.
Dubhe	62·3	Alphard	8·2
Schedar	56·0	Rigel	8·3
Benetnasch	49·8	Kiffa Borealis	9·0
Mirfack	49·5	Spica	10·6
Capella	45·9	Sirius	16·6
Menkalinan	45·0	Deneb-Kaitos	18·6
Arided or Deneb	44·9	Acrab	19·5
Almach	41·8	Antares	26·2
Vega	38·7	Adara	28·8
Castor	32·1	Fomalhaut	30·2
Nath	28·5	Phact	34·1
Alpheratz	28·5	α Phœnicis	42·9
Pollux	28·3	α Gruis	47·5
Alphacca	27·1	Canopus	52·6
Hamel	23·0	α Pavonis	57·1
Algeiba	20·4	Achernar	57·8
Arcturus	19·7	Tureis	58·8
Aldebaran	16·3	β Centauri	59·9
Denebola	15·2	α¹ Crucis	62·5
Markab	14·6	α Trianguli Australis	68·8
Algenib	14·6		
Ras Alhague	12·6		
Regulus	12·5		
Enif	9·5		
Altair	8·6		
Betelguese	7·4		
Procyon	5·5		
Menkar	3·7		

INTER-STELLAR DISTANCES—EPOCH, 1895.

ACHERNAR.

	° ′		° ′
Canopus (*α Argûs*)	39 24	—— (*α Pavonis*)	40 7
—— (*β Centauri*)	62 16	—— (*α Phœnicis*)	18 46
—— (*α Gruis*)	32 51		

ALDEBARAN.

	° ′		° ′
Alnilam (*ε Orionis*)	23 8	Nath (*β Tauri*)	16 45
Bellatrix (*γ Orionis*)	15 46	Phact (*α Columbæ*)	52 49
Hamel (*α Arietis*)	35 32	Rigel (*β Orionis*)	26 30
Menkar (*α Ceti*)	26 7		

USEFUL NAVIGATIONAL STARS—EPOCH, 1895.

(In order of Right Ascension).

Photometric Mags.	NAMES.	Right Ascension.	Declination.	Parallax.	Distance in Light Years.	Distance in Billions of Miles.
		H. M.	°	"		
2·1	Alpheratz (α *Andromedæ*)	0 3	28·5 N.	0·059	55	324
3·0	Algenib (γ *Pegasi*)	0 8	14·6 N.			
2·4	*——— (α *Phœnicis*)	0 21	42·9 S.			
2·2 to 2·8	*Schedar (α *Cassiopeiæ*)	0 35	56·0 N.	·036	91	532
2·1	Deneb-Kaitos (β *Ceti*)	0 38	18·6 S.			
1·0	*Achernar (α *Eridani*)	1 34	57·8 S.			
2·1	Almach (γ *Andromedæ*)	1 57	41·8 N.			
2·0	Hamel (α *Arietis*)	2 1	23·0 N.	·079	41	242
2·7	Menkar (α *Ceti*)	2 57	3·7 N.			
1·9	*Mirfack (α *Persei*)	3 17	49·5 N.	·087	37	220
1·0	Aldebaran (α *Tauri*)	4 30	16·3 N.	·101	32	189
0·2	*Capella (α *Aurigæ*)	5 9	45·9 N.	·095	34	202
0·3	Rigel (β *Orionis*)	5 10	8·3 S.	·040	81	478
1·9	Nath (β *Tauri*)	5 20	28·5 N.	·063	52	304
1·8	Alnilam (ε *Orionis*)	5 31	1·3 S.			
2·7	*Phact (α *Columbæ*)	5 36	34·1 S.			
1·0 to 1·4	Betelguese (α *Orionis*)	5 50	7·4 N.	·022	148	870
2·1	Menkalinan (β *Aurigæ*)	5 52	45·0 N.	·062	53	309
0·4	*Canopus (α *Argûs*)	6 22	52·6 S.			
−1·4	Sirius (α *Canis Majoris*)	6 41	16·6 S.	·388	8	49
1·5	Adara (ε *Canis Majoris*)	6 55	28·8 S.			
1·6	*Castor (α^2 *Geminorum*)	7 28	32·1 N.	·198	16	97
0·5	Procyon (α *Canis Minoris*)	7 34	5·5 N.	·341	10	56
1·1	Pollux (β *Geminorum*)	7 39	28·3 N.	·057	57	336
2·5	*Tureis (ι *Argûs*)	9 14	58·8 S.			
2·0	Alphard (α *Hydræ*)	9 22	8·2 S.			
1·4	Regulus (α *Leonis*)	10 3	12·5 N.	·089	37	215
2·5	Algeiba (γ^1 *Leonis*)	10 14	20·4 N.			
2·0	*Dubhe (α *Ursæ Majoris*)	10 57	62·3 N.	·046	71	416
2·2	Denebola (β *Leonis*)	11 44	15·2 N.	·029	112	660
1·3	*——— (α^1 *Crucis*)	12 21	62·5 S.			
1·2	Spica (α *Virginis*)	13 20	10·6 S.			
2·0	*Benetnasch (η *Ursæ Majoris*)	13 43	49·8 N.	Imme	asura	ble
1·2	*——— (β *Centauri*)	13 56	59·9 S.	Imme	asura	ble
0·0	Arcturus (α *Boötis*)	14 11	19·7 N.	·016	204	1196
2·1	*Kochab (β *Ursæ Minoris*)	14 51	74·6 N.	·022	148	870
2·7	Kiffa-Borealis (β *Libræ*)	15 11	9·0 S.			
2·4	Alphacca or Gemma (α *Coronæ*)	15 30	27·1 N.	Imme	asura	ble
2·9	Acrab (β^1 *Scorpii*)	15 59	19·5 S.			
1·1	Antares (α *Scorpii*)	16 23	26·2 S.			
2·2	*———(α *Trianguli Australis*)	16 38	68·8 S.			
2·2	Ras Alhague (α *Ophiuchi*)	17 30	12·6 N.			
0·2	*Vega (α *Lyræ*)	18 33	38·7 N.	·092	35	208
1·0	Altair (α *Aquilæ*)	19 46	8·6 N.	·214	15	89
2·1	*——— (α *Pavonis*)	20 17	57·1 S.			
1·5	*Arided or Deneb (α *Cygni*)	20 38	44·9 N.	Imme	asura	ble
2·4	Enif (ε *Pegasi*)	21 39	9·5 N.			
1·9	*——— (α *Gruis*)	22 2	47·5 S.			
1·3	*Fomalhaut (α *Piscis Australis*)	22 52	30·2 S.			
2·6	Markab (α *Pegasi*)	23 00	14·6 N.	·081	40	236

Note.—The stars prefixed by * are specially mentioned in B of Lecky's A B C Tables: with two exceptions, the declinations of the remainder come within the limits of upper portion of the same Table. Menkalinan having approximately the same declination as Arided, the tabular values will do for either; so the only one not provided for is Almach.
Where two mags. are given, the star is variable.

FIFTY USEFUL NAVIGATIONAL STARS—EPOCH 1895.

(In order of Declination.)

Northern Hemisphere.	°	Southern Hemisphere.	°
Kochab . . .	74·6 N.	Alnilam . . .	1·3 S.
Dubhe	62·3	Alphard	8·2
Schedar	56·0	Rigel	8·3
Benetnasch . .	49·8	Kiffa Borealis . .	9·0
Mirfack	49·5	Spica	10·6
Capella	45·9	Sirius	16·6
Menkalinan . . .	45·0	Deneb-Kaitos . . .	18·6
Arided or Deneb . .	44·9	Acrab	19·5
Almach	41·8	Antares	26·2
Vega	38·7	Adara	28·8
Castor	32·1	Fomalhaut . . .	30·2
Nath	28·5	Phact	34·1
Alpheratz	28·5	α Phœnicis . . .	42·9
Pollux	28·3	α Gruis	47·5
Alphacca	27·1	Canopus	52·6
Hamel	23·0	α Pavonis	57·1
Algeiba	20·4	Achernar	57·8
Arcturus	19·7	Tureis	58·8
Aldebaran	16·3	β Centauri . . .	59·9
Denebola	15·2	α¹ Crucis	62·5
Markab	14·6	α Trianguli Australis . .	68·8
Algenib	14·6		
Ras Alhague	12·6		
Regulus	12·5		
Enif	9·5		
Altair	8·6		
Betelguese	7·4		
Procyon	5·5		
Menkar	3·7		

INTER-STELLAR DISTANCES—EPOCH, 1895.

Achernar.

	° ′		° ′
Canopus (α *Argûs*)	39 24	—— (α *Pavonis*)	40 7
—— (β *Centauri*) . . .	62 16	—— (α *Phœnicis*) . . .	18 46
—— (α *Gruis*)	32 51		

Aldebaran.

	° ′		° ′
Alnilam (ε *Orionis*)	23 8	Nath (β *Tauri*)	16 45
Bellatrix (γ *Orionis*) . . .	15 46	Phact (α *Columbæ*) . . .	52 49
Hamel (α *Arietis*)	35 32	Rigel (β *Orionis*)	26 30
Menkar (α *Ceti*)	26 7		

Algenib.

	° ′		° ′
Markab (α *Pegasi*)	16 31	—— (α *Phœnicis*)	57 34
Schedar (α *Cassiopeiæ*)	41 41	Scheat (β *Pegasi*)	20 38

Alpheratz.

	° ′		° ′
Algenib (γ *Pegasi*)	13 58	Markab (α *Pegasi*)	20 12
Caph (β *Cassiopeiæ*)	30 6	Scheat (β *Pegasi*)	14 13
Hamel (α *Arietis*)	27 7	Schedar (α *Cassiopeiæ*)	28 1

Altair.

	° ′		° ′
Antares (α *Scorpii*)	60 13	Ras Alhague (α *Ophiuchi*)	33 32
Arcturus (α *Boötis*)	81 13	Scheat (β *Pegasi*)	49 17
Arided (α *Cygni*)	38 2	Schedar (α *Cassiopeiæ*)	72 59
Capella (α *Aurigæ*)	115 12	Spica (α *Virginis*)	97 53
Fomalhaut (α *Piscis Austr.*)	59 9	Vega (α *Lyræ*)	34 11

Antares.

	° ′		° ′
Acrab (β^1 *Scorpii*)	8 35	—— (α *Pavonis*)	51 21
—— (β *Centauri*)	42 00	—— (*Tri. Australis*)	42 42
Ras Alhague (α *Ophiuchi*)	42 7		

Arcturus.

	° ′		° ′
Alphacca (α *Coronæ*)	19 37	Ras Alhague (α *Ophiuchi*)	48 11
Antares (α *Scorpii*)	56 00	Spica (α *Virginis*)	32 50
Capella (α *Aurigæ*)	102 59	Vega (α *Lyræ*)	59 2
Denebola (β *Leonis*)	35 19		

Arided.

	° ′		° ′
Albireo (β *Cygni*)	22 18	Schedar (α *Cassiopeiæ*)	37 59

Bellatrix.

	° ′		° ′
Menkar (α *Ceti*)	35 38	Nath (β *Tauri*)	22 16

Benetnasch.

	° ′		° ′
Alphacca (α *Coronæ*)	30 35	Dubhe (α *Urs. Maj.*)	25 42
Arcturus (α *Boötis*)	30 37	Regulus (α *Leonis*)	58 20
Capella (α *Aurigæ*)	74 26	Vega (α *Lyræ*)	51 00

Betelguese.

	° ′		° ′
Achernar (α *Eridani*)	82 53	Phact (α *Columbæ*)	41 38
Adara (ε *Canis Majoris*)	39 28	Procyon (α *Canis Min.*)	26 00
Canopus (α *Argûs*)	60 32	Sirius (α *Canis Maj.*)	27 4
Nath (β *Tauri*)	22 16	Tureis (ι *Argûs*)	77 47

CAPELLA.

	°	′		°	′
Aldebaran (α *Tauri*) . . .	30	42	Nath (β *Tauri*)	17	29
Arided (α *Cygni*) . . .	78	11	Phact (α *Columbæ*) . .	80	15
Castor (α² *Geminor.*) . .	30	00	Regulus (α *Leonis*) . . .	69	30
Dubhe (α *Ursæ Maj.*) . .	49	17	Rigel (β *Orionis*) . . .	54	13
Menkalinan (β *Aurigæ*) . .	7	39	Schedar (α *Cassiopeiæ*) . .	42	30
Merak (β *Ursæ Maj.*) . .	51	23	——— (γ *Cassiopeiæ*) . .	39	34
Mirfack (α *Persei*) . . .	19	6			

CASTOR.

	°	′		°	′
Merak (β *Ursæ Maj.*) . .	43	3	Pollux (β *Geminor.*) . . .	4	30

FOMALHAUT.

	°	′		°	′
Achernar (α *Eridani*) . .	39	6	Markab (α *Pegasi*) . . .	44	51
Alpheratz (α *Andromedæ*) .	61	5	——— (α *Gruis*) . . .	19	48
Canopus (α *Argûs*) . . .	78	30	——— (α *Phœnicis*) . . .	21	50
Deneb-Kaitos (β *Ceti*) . .	26	46			

MARKAB.

	°	′		°	′
Scheat (β *Pegasi*) . . .	12	53	——— (α *Pavonis*) . . .	79	15

MENKAR.

	°	′		°	′
Deneb-Kaitos (β *Ceti*) . .	40	43	Rigel (β *Orionis*) . . .	35	12
Hamel (α *Arietis*) . . .	23	30			

PHACT.

	°	′		°	′
Adara (ε *Canis Maj.*) . .	17	31	Rigel (β *Orionis*) . . .	26	29
——— (κ *Orionis*) . .	24	29			

POLARIS.

	°	′		°	′
Aldebaran (α *Tauri*) . . .	72	51	Kiffa Borealis (β *Libræ*) . .	100	5
Algeiba (γ¹ *Leonis*) . .	70	29	Markab (α *Pegasi*) . .	74	21
Alphacca (α *Coronæ*) . . .	63	59	Menkar (α *Ceti*)	85	10
Alphard (α *Hydræ*) . .	98	50	Mirfack (α *Persei*) . . .	39	26
Alpheratz (α *Andromedæ*) .	60	19	Nath (β *Tauri*)	60	52
Altair (α *Aquilæ*) . . .	81	17	Pollux (β *Geminor.*) . .	61	50
Arcturus (α *Boötis*) . . .	71	30	Procyon (α *Canis Min.*) . .	84	35
Arided (α *Cygni*) . . .	44	41	Ras Alhague (α *Ophiuchi*) .	77	57
Benetnasch (η *Ursæ Maj.*) .	41	25	Regulus (α *Leonis*) . . .	78	20
Capella (α *Aurigæ*) . .	43	26	Schedar (α *Cassiopeiæ*) . .	32	48
Castor (α² *Geminorum*) . .	57	56	Spica (α *Virginis*) . . .	101	52
Denebola (β *Leonis*) . .	75	59	Vega (α *Lyræ*)	51	36
Dubhe (α *Ursæ Maj.*) . .	28	43	——— (γ *Ursæ Min.*) . .	18	52
Hamel (α *Arietis*) . .	65	48			

Algenib.

Markab (α *Pegasi*)	16° 31′	——— (α *Phœnicis*)	57° 34′
Schedar (α *Cassiopeiæ*)	41 41	Scheat (β *Pegasi*)	20 38

Alpheratz.

Algenib (γ *Pegasi*)	13° 58′	Markab (α *Pegasi*)	20° 12′
Caph (β *Cassiopeiæ*)	30 6	Scheat (β *Pegasi*)	14 13
Hamel (α *Arietis*)	27 7	Schedar (α *Cassiopeiæ*)	28 1

Altair.

Antares (α *Scorpii*)	60° 13′	Ras Alhague (α *Ophiuchi*)	33° 32′
Arcturus (α *Boötis*)	81 13	Scheat (β *Pegasi*)	49 17
Arided (α *Cygni*)	38 2	Schedar (α *Cassiopeiæ*)	72 59
Capella (α *Aurigæ*)	115 12	Spica (α *Virginis*)	97 53
Fomalhaut (α *Piscis Austr.*)	59 9	Vega (α *Lyræ*)	34 11

Antares.

Acrab (β^1 *Scorpii*)	8° 35′	——— (α *Pavonis*)	51° 21′
——— (β *Centauri*)	42 00	——— (*Tri. Australis*)	42 42
Ras Alhague (α *Ophiuchi*)	42 7		

Arcturus.

Alphacca (α *Coronæ*)	19° 37′	Ras Alhague (α *Ophiuchi*)	48° 11′
Antares (α *Scorpii*)	56 00	Spica (α *Virginis*)	32 50
Capella (α *Aurigæ*)	102 59	Vega (α *Lyræ*)	59 2
Denebola (β *Leonis*)	35 19		

Arided.

Albireo (β *Cygni*)	22° 18′	Schedar (α *Cassiopeiæ*)	37° 59′

Bellatrix.

Menkar (α *Ceti*)	35° 38′	Nath (β *Tauri*)	22° 16′

Benetnasch.

Alphacca (α *Coronæ*)	30° 35′	Dubhe (α *Urs. Maj.*)	25° 42′
Arcturus (α *Boötis*)	30 37	Regulus (α *Leonis*)	58 20
Capella (α *Aurigæ*)	74 26	Vega (α *Lyræ*)	51 00

Betelguese.

Achernar (α *Eridani*)	82° 53′	Phact (α *Columbæ*)	41° 38′
Adara (ε *Canis Majoris*)	39 28	Procyon (α *Canis Min.*)	26 00
Canopus (α *Argûs*)	60 32	Sirius (α *Canis Maj.*)	27 4
Nath (β *Tauri*)	22 16	Tureis (ι *Argûs*)	77 47

Capella.

	°	′		°	′
Aldebaran (α *Tauri*)	30	42	Nath (β *Tauri*)	17	29
Arided (α *Cygni*)	78	11	Phact (α *Columbæ*)	80	15
Castor (α² *Geminor.*)	30	00	Regulus (α *Leonis*)	69	30
Dubhe (α *Ursæ Maj.*)	49	17	Rigel (β *Orionis*)	54	13
Menkalinan (β *Aurigæ*)	7	39	Schedar (α *Cassiopeiæ*)	42	30
Merak (β *Ursæ Maj.*)	51	23	——— (γ *Cassiopeiæ*)	39	34
Mirfack (α *Persei*)	19	6			

Castor.

	°	′		°	′
Merak (β *Ursæ Maj.*)	43	3	Pollux (β *Geminor.*)	4	30

Fomalhaut.

	°	′		°	′
Achernar (α *Eridani*)	39	6	Markab (α *Pegasi*)	44	51
Alpheratz (α *Andromedæ*)	61	5	——— (α *Gruis*)	19	48
Canopus (α *Argûs*)	78	30	——— (α *Phœnicis*)	21	50
Deneb-Kaitos (β *Ceti*)	26	46			

Markab.

	°	′		°	′
Scheat (β *Pegasi*)	12	53	——— (α *Pavonis*)	79	15

Menkar.

	°	′		°	′
Deneb-Kaitos (β *Ceti*)	40	43	Rigel (β *Orionis*)	35	12
Hamel (α *Arietis*)	23	30			

Phact.

	°	′		°	′
Adara (ε *Canis Maj.*)	17	31	Rigel (β *Orionis*)	26	29
——— (κ *Orionis*)	24	29			

Polaris.

	°	′		°	′
Aldebaran (α *Tauri*)	72	51	Kiffa Borealis (β *Libræ*)	100	5
Algeiba (γ¹ *Leonis*)	70	29	Markab (α *Pegasi*)	74	21
Alphacca (α *Coronæ*)	63	59	Menkar (α *Ceti*)	85	10
Alphard (α *Hydræ*)	98	50	Mirfack (α *Persei*)	39	26
Alpheratz (α *Andromedæ*)	60	19	Nath (β *Tauri*)	60	52
Altair (α *Aquilæ*)	81	17	Pollux (β *Geminor.*)	61	50
Arcturus (α *Boötis*)	71	30	Procyon (α *Canis Min.*)	84	35
Arided (α *Cygni*)	44	41	Ras Alhague (α *Ophiuchi*)	77	57
Benetnasch (η *Ursæ Maj.*)	41	25	Regulus (α *Leonis*)	78	20
Capella (α *Aurigæ*)	43	26	Schedar (α *Cassiopeiæ*)	32	48
Castor (α² *Geminorum*)	57	56	Spica (α *Virginis*)	101	52
Denebola (β *Leonis*)	75	59	Vega (α *Lyræ*)	51	36
Dubhe (α *Ursæ Maj.*)	28	43	——— (γ *Ursæ Min.*)	18	52
Hamel (α *Arietis*)	65	48			

Procyon.

	° ′		° ′
Adara (ε *Canis Maj.*)	35 35	Canopus (α *Argûs*)	60 7
Alphard (α *Hydræ*)	30 21	Menkar (α *Ceti*)	69 1
Bellatrix (γ *Orionis*)	33 23	Pollux (β *Geminorum*)	22 49

Regulus.

	° ′		° ′
Algeiba (γ^1 *Leonis*)	8 20	Denebola (β *Leonis*)	24 38
Alphard (α *Hydræ*)	22 59	Procyon (α *Canis Min.*)	37 24
Betelguese (α *Orionis*)	62 27	Spica (α *Virginis*)	54 3

Sirius.

	° ′		° ′
Achernar (α *Eridani*)	68 58	Canopus (α *Argûs*)	36 15
Adara (ε *Canis Maj.*)	12 41	Phact (α *Columbæ*)	22 47
Alnilam (ε *Orionis*)	22 57	Procyon (α *Canis Min.*)	25 41
Alphard (α *Hydræ*)	40 20	——— (ι *Argûs*)	50 45

Spica.

	° ′		° ′
Algoreb (δ *Corvi*)	14 27	Kiffa Australis (α *Libræ*)	21 22
Antares (α *Scorpii*)	45 55	Ras Alhague (α *Ophiuchi*)	66 22
Denebola (β *Leonis*)	35 3	——— (α *Tri. Austr.*)	66 16
Kiffa Borealis (β *Libræ*)	27 33	——— (β *Centauri*)	49 44

Vega.

	° ′		° ′
Alphacca (α *Coronæ*)	39 42	Ras Alhague (α *Ophiuchi*)	29 35
Arided (α *Cygni*)	23 51	Spica (α *Virginis*)	87 46

Various.

	° ′	
Kiffa Australis (α *Libræ*)	9 10	Kiffa Borealis (β *Libræ*).
Ras Alhague (α *Ophiuchi*)	39 45	Alwaid (β *Draconis*).
Ras Alhague (α *Ophiuchi*)	39 11	Etanin (γ *Draconis*).
——— (α *Trianguli Australis*)	19 7	——— (β *Centauri*).
——— (α *Tri. Austr.*)	26 23	——— (α *Pavonis*).
——— (δ *Cygni*)	16 9	——— (ε *Cygni*).
——— (α *Gruis*)	18 26	——— (α *Pavonis*).
Deneb-Kaitos (β *Ceti*)	24 36	——— (α *Phœnicis*).

Note.—Though the foregoing inter-stellar distances are computed for 1895, there will be no change of any consequence for a great many years to come.

CHAPTER III.

LATITUDE BY MERIDIAN ALTITUDE.

In setting about the working of any *astronomical* question in navigation, *the invariable thing to start with is* THE GREENWICH DATE.* All the elements in the *Nautical Almanac* are computed *for noon at the meridian of the Royal Observatory at Greenwich.* Consequently, if an observation be taken *elsewhere,* it becomes necessary to reduce the astronomical data of the calculation to the time at Greenwich corresponding to the instant of observation at the place where it is made.

The Greenwich Date.

In the case of the problem under consideration, the only Nautical Almanac element which requires reduction is the sun's declination. This is frequently done by inspection (Table 19 of Raper); but the writer prefers, as the simpler plan of the two, to look at the chronometer as soon as "eight bells" has been made, and from the Greenwich Mean Time thus found, to correct the declination (taken from page II. for the month) by the hourly difference, in the same way as for an ordinary morning sight.

Easiest mode of correcting Declination.

By this means, as the application of the correction is self-evident, there is less liability to mistake than by the use of the table—markedly so when the sun is very near the equator, and the *correction* for Greenwich time happens to exceed the declination itself.

Also, why burden the memory with *two* rules, when *one* is sufficient? The man who can correct his declination for morning or afternoon sights, needs no other method to enable him to correct it for his noon observation; in each case the *object* is the same, and there is no occasion to alter the *process.*

In general, a little mental arithmetic is all-sufficient to calculate

* For quick reference to the *Nautical Almanac,* it is a good plan, month by month, to cut off half an inch or so of the top right-hand corner, so that the book can at once be opened at pages I. and II. for the current month.

this correction, and at the summer and winter solstices, when the change of declination is slow, it can be taken out at sight.

Mean and Apparent time pages in Nautical Almanac.

It must be borne in mind that the right-hand page of the *Nautical Almanac* contains the elements for *Mean* time, and that the left-hand page is adapted to *Apparent* time; consequently, whether the reduction in this or any other problem is to be made to Mean or Apparent time, the declination must be taken from the corresponding page.

The column of *Variation in one hour* is only to be found on the left-hand page, and is common to both.

In all the astronomical problems, it will be found handy to work by decimals. Thus, to find the correction for 4 hours and 6 minutes of Greenwich Mean Time, when the variation of declination in one hour is 43″·68, proceed as follows:—

```
Hourly diff.......... 43″·7
G.M.T................× 4·1
                      -----
                       437
                      1748  Correction
               60 ) 179″·17 ( 2′ 59″·2
                    120
                    ---
                     59
```

In this example, the second decimal figure is dropped as being needlessly exact; and the first decimal figure thrown up to suit.

To find the decimal parts of an hour equal to any given number of minutes, divide the latter by 6. Thus 6 minutes equal ·1 of an hour; 30 minutes equal ·5; 45 minutes equal ·75; 3 minutes equal ·05 of an hour, and so on.

Definition of Latitude.

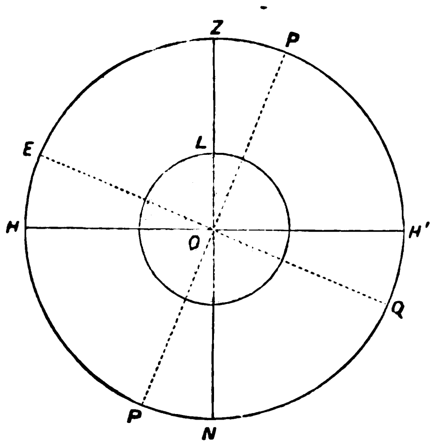
Regarding the earth as truly spherical, the LATITUDE of a place is the angle subtended at the centre of the earth by *the arc of the meridian* extending from the Equator to the place in question. Nothing can be simpler than this definition. As a corollary to it we have another simple statement:—*The altitude of the elevated Pole above the true horizon is equal to the observer's Latitude;* and since the earth's rotation on its axis does not alter the position of the Pole, the altitude of the Pole is necessarily a constant at any given point on the earth.*

* A few pages further on, this last statement about the constancy of the Pole will be found slightly modified. Except as a matter of purely scientific interest, the Navigator need not trouble himself about the wanderings of the earth's rotation axis

The following diagram and explanation will make this as clear as daylight.

Z represents the zenith of the observer at O, N the nadir, PP the poles, EQ the equator, HH′ the horizon. The outer circle is the celestial concave, and the shaded part is the earth, projected on the plane of the meridian.

Then ZE is the arc of the meridian intercepted between the Zenith of the place and the Equator, and is therefore equal to the Latitude, also PH′ is the altitude of the Pole.



Now PE is equal to 90°, and ZH′ is equal to 90°; therefore, PE is equal to ZH′. Take away the common part ZP. Then ZE is equal to PH′, or, the latitude is equal to the altitude of the elevated Pole.

Some men drift into a very common though extremely reprehensible habit of finding the sun's meridian zenith distance by subtracting their noon altitude from the constant 89° 48′; *and this they do under all circumstances*—whether they are standing on the bridge of a high-sided steamer, or the deck nearly awash of a coasting schooner—whether the sun is almost overhead, or only a few degrees above the horizon. Some do it through pure ignorance—others, because never having taken the trouble to investigate the matter, think "it is near enough." But it is *not* near enough; and the man who does such a lazy trick, to save himself at most half-a-dozen figures, is not fit for command. **Rough and ready 89° 48′.**

The proper mode for sea practice, where conciseness is only second to accuracy, is to make use of Table 38 in *Raper's Epitome*, which, however, be it noticed, is calculated for observations of the *lower* limb only. **Table 38 of Raper.**

This tabular correction comprises the joint effect of dip, refraction, parallax, and semi-diameter; but as the latter is a variable quantity, depending upon the earth's distance from the sun,* the correction should in strictness be itself corrected in accordance with the time of the year; but as this secondary correction for variability of the sun's semidiameter never exceeds 0'·3—and is mostly much less—no great harm is done by neglecting it.

Correction of meridian altitude.

Therefore, to correct the observed meridian altitude, apply first the centering error of the sextant, then the index error, if any—which can *always* be done mentally—and to the result add the *correction* from Table 38. This amount subtracted from 90° gives the zenith distance, to which apply the *reduced* declination in the usual way.

As an example of the consequences which might ensue from the use of this slipshod 89° 48', the very possible case will be taken of a vessel bound to Glasgow, entering the North Channel in the month of December. To shew the difference, the latitude will be worked both correctly and loosely.

EXAMPLE.

At noon on Saturday, December 18th, 1880, 0·30 P.M., G.M.T. by Chronometer, being in latitude by account 55° 30' North, and longitude by account 7° 40' West, observed the meridian altitude of the sun's lower limb to be 10° 51¼'. No centering error (very unlikely). No index error. Height of the eye 32 feet. Weather inclining to be thick, with passing drizzles of rain; moderate gale at S.W., freshening gradually.

Rough and ready method supposed to be "near enough."

Constant	89° 48'
Obs. altitude	10 51¼
Zen. dist.	78° 56¾' N.
Declination	23 25¼ S.
Latitude................	55° 31½' North.

Short but correct method.

Obs. altitude	10° 51¼'
Corr. Table 38 +	6
	10° 57¼'
	90
Zen. dist.	79° 2¾' N.
Declination	23 25¼ S.
True latitude .	55° 37½' North.

The difference in the work of the two methods amounts to *four figures*, but the difference in the resulting latitude amounts to *six miles*. This, however, is not all—mark what follows.

"Read, mark, learn, and inwardly digest."

About a quarter past ten same morning, when the sun had an altitude of 8°, sights were got for longitude, which were worked up as soon as the necessary latitude had been obtained at noon. Now, at the time the sights were taken, from the sun being so far to the southward, an error of *one* mile in the latitude used for the calculation would produce an error of exactly 4' (minutes)† of longitude—in this case *to the eastward;* and since the error of

* The earth is nearest to the sun during the northern winter, and the apparent diameter of the sun then greatest. It is least in July.

† It will be noticed that the word "minutes" is used here instead of "miles." The latter would be decidedly incorrect. *In speaking of Longitude or the divisions of the Sextant,* it is proper to say degrees (°), minutes ('), and seconds ("); strictly speaking, the same thing applies to latitude also, but as a mile of latitude and a nautical mile are

latitude, as shewn in the preceding example, amounts to six miles, the corresponding error deduced from forenoon sights would be 24′ (minutes) of longitude, equal to 13½ miles of distance. Consequently, the ship would be 6 miles further north and 13½ miles further east than her captain supposed her to be. Now, assuming the longitude at noon as determined by chronometer to be 7° 25′ West, and the latitude 55° 31½′ North, according to the "near enough" method, the ship would *apparently* be about 9 miles *north-westward* from Inistrahull, whereas her *true* position would be in latitude 55° 37½′ N., and longitude 7° 1′ W., or some 14 miles to the *north-east* of Inistrahull. Meanwhile the weather rapidly gets thicker, but the captain, feeling satisfied with his observations, and knowing his chronometers cannot be "out" on the short passage from a North American port, runs on with confidence, only to find, in less than three hours, his vessel a total wreck on the rock-bound coast of Islay.* In the Board of Trade enquiry which would be sure to follow, the bewildered captain—if he survived—would probably seek to account for the accident by an unknown error in the compasses, or the influence of a mysterious current. The Court, ignorant of the 89° 48′ transaction, would perhaps be equally puzzled to know how the ship got so far out of her course after such an apparently good "Fix" at noon; but in any case it would very properly suspend him for not having verified his position by the lead; and now that Lord Kelvin's invaluable sounding machine enables this to be done without stopping the ship, there is no excuse for the omission. Those who have a blind faith in "sights," without understanding the groundwork of the thing, should take this lesson to heart.

Declination at noon—*ship time*, must be reduced to corresponding time at Greenwich.

Doubtless to some the foregoing will appear an exaggerated case, but it is not so. Further, there are men holding Master's certificates who are in the habit of applying the declination (as given in the *Nautical Almanac*) to their noon sight for latitude, without using any correction whatever for the ship's longitude, or, in other words, without reducing it to Greenwich time. They think that the precept, "At apparent noon," heading page I., means that the subjoined declinations, &c., are good for noon *at any place.*

Mere "cramming" to pass examination deprecated.

One would imagine that, with the strict examinations now in force, such misapprehension would be impossible. When we recollect, however, that many worthy young men brought up before the mast, have absolutely no groundwork of education, and pass merely by dint of *hard cramming*, there is no longer occasion to be surprised. Moreover, having obtained their certificates, years may pass before they are called upon to fill a posi-

practically the same thing all over the world, the looseness of expression is in this last case more pardonable.

* It could be shewn in the same manner, that if the *altitude* were but 1′ wrong, and the resulting error in the longitude happened to lie on the same side as the error due to the incorrect latitude, the mistake in the ship's position would be still greater, since 1′ of altitude in the case before us is equal to 18^s of time, or 4½′ of longitude.

Rusty Navigators.

tion requiring navigational knowledge; and in the interval they become rusty, and the most of what they have learnt is forgotten.

In the case of finding the latitude just given, it so happened that the declination required no reduction. Let us, then, take an example of a different kind, and work it as recommended for sea practice.

EXAMPLE II.

September 15th, 1880, in longitude by account 74° 30′ West, the meridian altitude of $\underline{\odot}$ was 53° 52′, the observer being North of the sun, and the height of his eye 24 feet. Centering error − 30″. Index error − 3′ 24″. When the sun had ceased to rise, the G.M.T. by chronometer was 4h. 54m. 10s. P.M. same date. Required the latitude.

Declin. page II. N.A., Sept. 15th	2° 47′ 3″·5 N.	*decreasing.*
Reduction for Greenwich date .	− 4 43 ·7	
Corrected declination .	2° 42′ 19″·8	

Observed altitude $\underline{\odot}$.	53° 52′	
Centering error − 30″ } Index error − 3′ 24″ }	− 4	
	53 48	
Correction table 38 . .	+ 10½	
True Altitude	53 58½	
	90	
Zenith distance . . .	36 1½	N.
Corrected declination .	2 42¼	N.
Latitude . .	38° 43¾′	North.

Var. in 1 hour	57″·9
G.M.T. .	× 4·9
	5211
	2316
	correction
60)283″·71(	4′ 43″·7
	240
	43

With low altitudes observe sun's upper limb.

When the sun's altitude is low, as in winter, it is advisable to observe the *upper* limb, as being further removed from the influence of the excessive refraction so capricious near the horizon. It is true the after calculation is somewhat lengthened by so doing, and the difference of altitude is not much; still, every little tells, and a trifle in the way of extra labour, when a benefit is to be gained, should not be allowed to weigh for an instant.

Inverting telescope.

In the use of the sextant, the observer should accustom himself from the commencement to the *inverting* telescope. It is rather difficult to manage at first, but practice makes perfect, and its superiority over the direct one is unquestioned.

Hack watch set to Greenw. Mean Time.

At sea, it is a good plan to carry a watch set to *Greenwich Mean Time.* If a common one, it can be regulated every morning when winding the chronometers, but if this be objectionable on the score of the watch's value, it is easy to ascertain its error and make a mental note of it. This watch, then, becomes available for azimuths, ex-meridians, or other work where the exact second is not of consequence, and saves a journey to the chronometer. To have it set to *Apparent Time at Ship* might at first sight be considered preferable, but a moment's reflection will shew that this is continually altering, and in a fast steamer, on east or west courses in high latitudes, does so very rapidly, sometimes as much as 50 minutes in a day, so that the watch would never be correct for an hour on a stretch. Moreover the G.M.T. can with ease be converted into Apparent Time at Ship, Sidereal Time, or any other, just as occasion may require. A strong watch, with watertight case, which will stand knocking about and yet go sufficiently well for this purpose, can be purchased now-a-days for thirty shillings or two pounds; it should be of the kind known as "keyless," or what the Americans call a "stem-winder."

Proper time of regulating clocks on board.

After breakfast all the *clocks* on board should be set to Apparent Time at Ship for *noon* of that day, as determined in advance, by working up the dead reckoning. There is then no fear of missing "sun time," and the plan for many reasons is preferable to the usual one of making eight bells by the sun.

For example, when steering near North or South in the fly-away steamers of to-day, it would shew immense ignorance to wait till the sun had "dipped" and take the *maximum reading* as the *meridian altitude.*

Sun and ship approaching each other.

It does not require much "savvee" to see that near the meridian the apparent "rise" due to speed of ship will exceed the real "rise," and that up to a certain point it will neutralize the subsequent drop. By the time this point has been attained it may be several minutes after the meridian passage, and the sun may bear several degrees to the westward.

With the moon it is still worse, since her rapid motion in declination must be taken into account. When the sun is crossing the equator, his hourly change in declination is only 1′, but the moon's is 18′. Take the case of a "20-knotter" in latitude 50° N., steering towards the moon, which is crossing the equator northwards. They will approach each other at the railway speed of 38′, and the *maximum* altitude will exceed the *meridian* altitude by very nearly 3¾′, and will occur at 11½ minutes after the time of meridian passage.

This is one reason why the moon is tabooed in "Wrinkles." The author notices with amusement that certain of the "old-timers" have taken the hint and toned down as to the utility of our satellite for navigational purposes.

A 35-knot "Destroyer" in a hurry.

Now let us look at the problem the other way about. Sticking to same Latitude, imagine a 35-knot "*Viper*" to be steering true North, and the Moon to be crossing the Equator going South: they would be *receding* from each other at the express speed of 53 knots (61 statute miles). In this case the maximum alt. would occur fully 16 mins. *before* the meridian passage, when the moon's bearing was S. 5¼° E.; and the correction to be *added* to the maximum alt. to reduce it to the meridian would be close upon 7¼′,—both rather serious items as affecting safe navigation.

Moon and ship receding from each other.

When *really* on the meridian (bearing South) the moon would *appear* to be falling smartly, owing to the steady rise of the *Southern* horizon as it followed up the ship in her progress to the North. (*See* page 337, lines 5, 6, and 7 from top.)

This is an extreme, though not impossible, case, since we have (January, 1900) a "Destroyer" of the above speed.

Inferior transit of a circum-polar star.

Though the principle remains the same, Meridian Alts. *below* the pole must be treated differently. As shown in Chapter IV., Part II., the meridian alt. (to a stationary observer) is the *minimum* alt., but the sweet simplicity of this problem also is liable to be interfered with by the speed of a fast vessel steering towards or away from the object—probably a high declination star. Should the ship be *approaching* the star, its alt. is *increased* by what may be regarded as the continuous dropping away of the horizon, and the *minimum* is therefore reached *before* the actual meridian passage. Should the ship be receding, the converse happens. Luckily a star's declination is constant, so the errors are less than with the *in*constant moon.

Remember that the altitude of a celestial body is the angular distance *between the body and the horizon*, and that the alt. may be increased or diminished by a change in the place of either or both. For example, though the ship be stationary, the merid. alt. would have a different value to an observer aloft as compared with an observer on deck, owing solely to the difference in the place of the two horizons. Religiously bear in mind also the paragraph following the example on page 394.

Now, the reader will want to know what to do should he find himself unwittingly interfering with the sun's normal arrangements for passing the meridian at high noon. There is a choice of two things.

When to make eight bells.

1. Set clock to Apparent time at Ship for noon position, as already recommended, and make eight bells by it. Then, whatever the altitude may be at that moment, accept it as the *meridian* altitude, even though the sun be still on the rise. Work out the Latitude as usual.

2. Continue observing till the sun has ceased to rise; then note time by chronometer and work out the maximum altitude as an "Ex-meridian."

For general convenience, and also as being better adapted to ship-routine, the author has no hesitation in recommending No. 1, provided the clock is correctly set in the forenoon, and is not in the habit of losing or gaining a handful of minutes per hour. *Accurate* navigation is not so easy as some people think: there are many pitfalls to trap the unwary.

LATITUDE BY MERIDIAN ALTITUDE OF A STAR.

Observations of the stars should be industriously practised.

Transatlantic passages made solely by dead reckoning!!!!!

The advantage possessed by a man who is well posted in this work, over another who is ignorant of it, cannot be over-estimated. One now and again hears it remarked by old Atlantic navigators, that they have frequently been compelled to make the passage from land to land entirely by dead reckoning, as sights were not to be had. As it is inconceivable that during nine or ten days neither the sun nor stars should ever have been visible, this assertion must surely mean that the sun failed to present himself precisely at the orthodox times of 9 A.M. and "high noon;" and when appearing at other hours, could not be utilized for want of a known problem suitable to such irregular visits. Moreover, the stars must have been looked upon only as *theoretical* aids to navigation, being, for *practical* work, quite unreliable. It is hoped a better system of education may serve to dispel such illusions, and that every man in the future will fit himself to take advantage of the heavenly bodies, which are available for his guidance *at all times* when visible.

The problem of finding the latitude by meridian altitude of a star should be more frequently practised, especially when making the land in high latitudes during the winter months. As before stated, morning or evening twilight offers the best horizon for star observation, and reference to Table 27 and 27A of *Raper* will give the names of those on the meridian at that time.

Star observations best during twilight

The Ex-meridian Tables of Brent, Walter, and Williams contain similar information.

As it may be difficult to bring the star down to the horizon if there is over-much light in the sky, it will be found a capital plan to calculate its meridian altitude beforehand, and having set the sextant to this angle, direct the sight a few minutes before the time of transit to the north or south points of the horizon, as the case may be, and the star's image will be seen either upon or near the horizon. There is then no difficulty in bringing it exactly to the horizon, and keeping it there like the sun, till its greatest altitude is attained, which being read off will give very simply, and with exceedingly few figures, the sought-for latitude.

How to find the star required.

The simplicity of this observation is perfectly delightful, *and the star cannot be mistaken,* as no other (except, perhaps, telescopic stars) will have the same meridian altitude at that time. It frequently happens that, by this method, a most perfect observation can be made during twilight, when the unaided eye will entirely fail to pick the same star out in the general brightness of the sky, and it possesses the additional advantage—*that the observer does not even require to be acquainted with the star he is taking.* For this observation, either the inverting or direct telescope may be used; but, as already stated, the first-named is preferable. If, however, the observation be made *after dark,* it will be necessary to employ the *star telescope;* and with regard to this, it may be said that one of inferior quality is worse than none at all.

Star's previous recognition by eye unnecessary.

To find the approximate meridian altitude of the star by previous calculation is an easy thing.

How to *calculate* meridian altitude.

Work up the latitude by dead reckoning, and by subtracting it from 90° find the co-latitude. If the star's declination and the co-latitude be of the same name, add them together; or take their difference if of contrary names. The result is the meridian altitude, to be reckoned from the south point of the horizon when the latitude is north, and the contrary when south. But should the sum exceed 90°, it must be taken from 180°. This last shews that the observer is on the equatorial side of the star, and in that case the altitude must be reckoned from the north in north latitude, and from the south in south latitude.*

EXAMPLE I.

Example of calculating meridian altitude.

About 8·15 P.M., June 1st, 1881, being in latitude by account 47° 10′ N., wished to observe the star Spica for latitude. On referring to Table 27, it is found to pass the meridian on that day about 8·39 P.M. Apparent Time at Ship. Required its approximate altitude at that time, to which to set the sextant.

Latitude	47°	10′	N.	
	90			
Co-latitude . . .	42	50	N.	
✱'s Declination . .	10	32¾	S.	See page 345, N.A.
Approx. merid. alt.	32°	17¼′	S.	

EXAMPLE II.

About 4 P.M., July 16th, 1881, being off the Horn, in latitude by account 54° 10′ S., wished to correct the dead reckoning by an observation of the star α Crucis, which by Table 27 will pass the meridian on that day about 4·35 P.M. Apparent Time at Ship. Required the star's approximate altitude at that time, to which to set the sextant.

Latitude	54°	10′	S.
	90		
Co-latitude	35	50	S.
✱'s Declination . . .	62	27	S. See page 343, N.A.
✱'s Meridian altitude .	98	17	reckoned from the North.
	180		
✱'s Meridian altitude .	81°	43′	reckoned from the South.

* In the N. A. for 1895, the Right Ascensions and Declinations of the stars will be found between pages 308—371.

Its declination will always be a guide as to the direction in which to look for a star. According as the former is North or South of the observer's position, so will the latter bear when on the meridian. This is so self-evident that there is no occasion to tax the memory by recollecting the rule given further back.

In looking for a star, be guided by its declination.

We will now suppose the observation of Spica (Example I.) to have been completed, and that the observed meridian altitude was ascertained to be 32° 22′ S.; eye 30 ft.; no centering error; no index error. Required the latitude.

Observed altitude	32° 22′	S.
Correction—Table 38 of Raper . . .	− 6¾	
True altitude	32 15¼	
	90	
Merid. zenith distance	57 44¾	N.
✱'s Declination	10 32¾	S.
True latitude	47° 12′	North.

This is even shorter and simpler than the latitude by meridian altitude of the sun, *since the star's declination being almost a fixed quantity, requires no correction for Greenwich Mean Time.*

Star's declination a fixed quantity.

The lower portion of Table 38 of Raper gives the sum of the corrections for a star in the same manner that the upper portion answers for the sun. It may also be used for correcting the observed altitudes of any of the planets (except the moon), as their semi-diameter and parallax in altitude are not worth consideration: consequently, the operation of finding the latitude by a planet is precisely similar to that by the star Spica, worked out above.

Correction of altitude.

The declination of the planets, and their *mean* time of passing the meridian, will be found in the N. A. for 1895, between pages 234—265, under the heading "Mean time." Since the declination of the planets is continually changing, note the time by chronometer when the meridian altitude is observed, and reduce the declination to the Greenwich date by simple proportion. As the "hourly variation" is not given, it will be necessary to take the "variation" for one whole day, and then say—As the change is in 24 hours, so will the change be in the given number of hours.*

Planets' declination continually changing.

* If a rigorously exact reduction be required for any special purpose, "second differences" would have to be employed see page 508 in N. A. for 1895; but for sea use such ultra-refinement is thrown away.

EXAMPLE III.

July 3rd, 1881, at 7·39 A.M. *Mean* Time at Ship, in longitude 104° 6′ W., let the observed meridian altitude of the planet Mars (♂) be 22° 50′ N., when a chronometer showed 2h. 35m. 58s., G.M.T., same date. Eye 32 feet; no centering error; no index error. Required the latitude.

Declin. noon July 3rd	13° 4′ 3″ N.	Page 245 N. A.
Declin. noon July 4th	13 18 3 N.	„ „
Change in 24 hours	0 14′ 0″	

If the change is 14′ in 24 hours, what will it be in 2·6 hours?

24h. : 2·6h. : : 14′ :
14′
2·6
———
84
28
24) 36·4 (1′·5
24
———
124
120

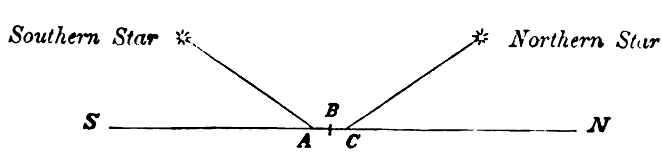
Declin. July 3rd . . .	13° 4′ 3″ N.
Correction for 2·6 hrs. .	+ 1 30
Reduced declin. . . .	13° 5′ 33″ N.
Observed merid. alt. . . .	22° 50′ N.
Correction—Table 38 of *Raper*	− 7¾
True alt.	22 42¼
	90
Merid. zenith dist.	67 17¾ S.
Corrected declination . . .	13 5½ N.
Latitude	54° 12¼′ South.

Observe stars on *both* sides of zenith.

Whenever you can, it is advisable to take stars *both North and South of the observer*, as by so doing all systematic errors, of whatever nature, are eliminated from the *mean* of the results. For example, some men have a *fixed habit* of bringing the object too low—others, not low enough; the astronomical refraction may be greater or less than the amount allowed in the Tables; the instrumental error may be somewhat different to what is supposed; or the horizon may be unduly elevated or depressed, as already explained in a previous chapter.

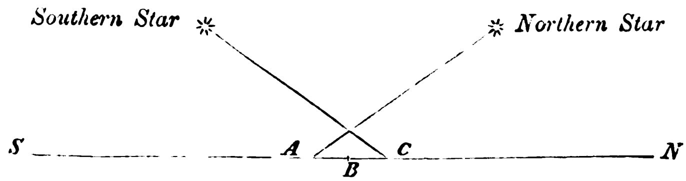
Compensation of errors.

In each and all of these cases the certain cure is to observe stars on both sides of the zenith. If the ultimate effect of these various errors lies on the side of making the altitudes *too great*, the northern star will give the latitude too far north, and the southern star will give it too far south; but the *mean* of the two will be correct, or nearly so.



In the diagram, the balance of error in the case of the northern star places the ship at *C;* and as the error is common to both observations if they are taken nearly at the same time, the southern star will place the ship at *A*. In reality she is at *B*, or about midway between the two.

In like manner, if the errors conspire to make the observed altitudes *too small*, the northern star will give the latitude too far south, and the southern star will give it too far north, but the *mean* will be correct as before. The subjoined diagram shews this.



It is well to recollect that the greater the meridian altitude, the greater the correspondence between the latitude of the observer and the declination of the body observed, and *vice versâ;* or, in other words, as we approach an object its altitude increases.

Shifting of polar axis.

In a footnote near the beginning of this chapter, reference was made to what is now termed "the inconstancy of latitude." Until comparatively recently it was a canon in astronomy, that once the latitude of a place had been determined with all the refinements known to science, a shift was impossible. But it seems now that though the statement is *very nearly* true, it is not absolutely so.

Theoretical investigations, indeed, have long given rise to the hypothesis of changes of latitude, but the first *observational* data confirmatory of this were obtained by Professor F. Küstner, who, from his observations at the Berlin Observatory, showed that the latitude of Berlin in the spring of the year 1882 was about two-tenths of a second less than at the same time of the year 1881. Similar results were derived from the observations at the Observatories of Pulkova and Gotha. In September, 1888, therefore, the Conference of the Permanent International Geodetic Commission, which was held at Salzburg, determined to undertake an investigation of this important question by means of simultaneous observations at the Observatories of Berlin, Potsdam, Prague, and Strasburg, which were commenced in January 1889, and continued until April, 1890. The result of these observations was to show that in fact the latitudes of the places named were subject to periodical changes, the maxima of which occurred during the autumn, and the minima during the spring-time. The greatest variation amounted to about one-half of a second (0″·5), or in linear measure about 50 feet.

Variations of this extent could not be neglected in accurate geodetical measurements, where the calculations are often worked out to a few hundredths of a second.

Inconstancy of latitude.

Theoretically, there are three possible reasons for variations in latitudes, viz., changes of gravity or of the plumb-line, the still unknown vibratory movements of the Earth's axis; and lastly, variations in the position of the Earth's rotation axis *in the mass of the Earth itself.* For the determination of this question it is necessary to have corresponding observations for latitude at two stations, as nearly as possible 180° distant from each other.

In case it should be, as in fact did happen, that the variation of latitude takes place simultaneously, but in an opposite sense, the third explanation is the only one possible.

The Permanent Commission for Earth-Measurement determined, therefore, in January, 1891, to despatch an astronomical expedition to Honolulu for the purpose of taking observations for latitude as accurately as possible, simultaneously with observations at the observatories of Berlin, Prague, and Strasburg. The expedition, under Dr. A. Marcuse, left Berlin on April 1st, 1891, and at Washington was joined by Mr. Preston, an officer of the Coast and Geodetic Survey of the United States.

From the end of May, 1891, to May, 1892, Dr. Marcuse recorded 1800 observations for latitude, with the result that if, for Germany, the geographical latitude increases, it decreases on the anti-meridian to exactly the same extent; thus furnishing an incontrovertible proof that the variations of latitude are caused by changes in the earth's rotation axis. The greatest possible precautions were taken to insure the accuracy of the measurements. The station was situated on a coral-rock on the sea-coast; the observation hut was specially constructed with double walls to keep off the intense rays of the sun; and in order to guard against irregular refraction and the influence of temperature on the zenith telescope, the electric light was used for reading the instruments.

Observing station.

There are two terms of latitude variation, whose periods are respectively one year, and 428·6 days.

On December 3rd, 1892, at the meeting of the Berlin Geographical Society, Dr. Marcuse read a report upon the geodetic expedition to the Hawaii Islands above referred to, and, as may be imagined, much interest was evinced. There are, however, a good many astronomical experts who require further evidence before regarding the matter as finally settled.

CHAPTER IV.

LATITUDE BY MERIDIAN ALTITUDE BELOW THE POLE.

We now come to a useful problem, which is very little practised, though it is just as simple, and certainly as short, as any of the preceding.

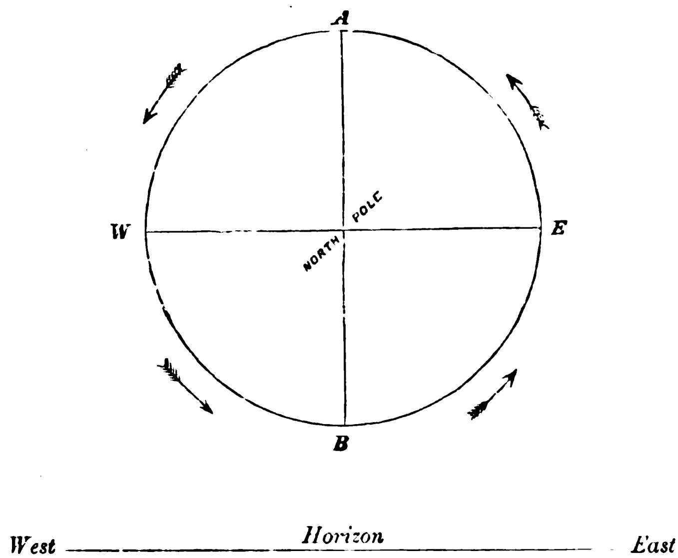
Circumpolar stars—their course in the heavens.

In high latitudes, certain stars complete their daily revolution round the pole of the heavens without rising or setting, and are consequently termed *Circumpolar stars.* This occurs when their polar distance is less than the latitude of the observer—both being of the same name. These stars having come to the meridian above the pole, which is their highest point, decline towards the westward for six hours, when they gradually curve eastward—still falling, however—till in another six hours their lower culmination is reached, when they are said to be *on the meridian below the pole.*

They then commence to rise, still moving eastward, for another six hours, after which they turn to the westward in their upward course for a further period of six hours, when the circle is completed, and they are again on the meridian *above* the pole. The hours alluded to here are of course *Sidereal* hours, which are nearly ten seconds shorter than mean solar ones.

Azimuths—seeming anomaly when meridian distance is greater than six hours.

It will be noticed that during the *lower* half of the star's journey their motion is from *west* to *east.* Attention is particularly called to this, because in observing star azimuths, unless acquainted with it, a beginner is likely to fancy he has made a mistake on discovering that, as his *western* hour angles grow larger after they have exceeded six hours, the star's bearing becomes more *easterly,* which at first sight seems opposed to what one would expect. The annexed diagram makes the explanation clear.



Diurnal circle.

$A\,WBE$ is the diurnal circle of a northern circumpolar star, and the line AB represents the meridian of the observer. At A the star is at its upper culmination, or, in other words, it is on the meridian *above* the pole, and bears North. During the first six hours, whilst passing from A to W, it falls towards the *westward;* at W, therefore, the hour-angle of the star is 6 hrs. west. During the second six hours, between W and B, it falls towards the *eastward.* At B it is at its lowest culmination, or, in other words, it is on the meridian *below* the pole, and again bears North. During the third six hours, between B and E, it rises towards the *eastward;* at E the star's hour-angle may be expressed either as 18 hrs. west or six hrs. east of the meridian. And during the last six hours its course is upwards, and towards the *westward,* till, after a lapse of 24 sidereal hours, it again transits at A. For southern circumpolar stars the direction of the arrows must be reversed and the letters E and W change sides.

Distance of North Star from the Pole.

If the night be cloudless, it is easy in the northern hemisphere —without reference to the compass—to tell when a star is near the meridian below the pole, by its being vertically under the Pole star, which latter is now only $1\frac{1}{4}°$ distant from the pole itself.

In observing the meridian altitude *below* the pole, the sextant readings get *less and less,* until the lowest point is reached, when the star may be said to be "down," in the same sense that at noon we say the sun is "up."

Rule for finding the Latitude.

To find the latitude, correct the altitude by Table 38 of Raper. Find the star's polar distance by subtracting the declination from 90°. Add together the polar distance and the true altitude, and the result is the latitude, without further trouble. *It would be a puzzle to find anything more easy.*

EXAMPLE.

Entering Channel after a couple of days of cloudy weather, the sky partially cleared to the northward about 8 o'clock in the evening of November 6th, 1881, when the meridian altitude of star Dubhe *below* the pole was observed to be 21° 58′. Eye, 24 feet. No arc error. No index error. Required the latitude.

Dubhe's declin. Nov. 6th	62° 23′ N. (page 340, N. A.)		
	90		
Dubhe's polar distance	27 37 N.	*'s observed alt.	21° 58′ N.
„ true altitude	21 51 N.	Correction (Table 38)	— 7
Latitude	49° 28′. North.	*'s true altitude	21° 51′

How to calculate Meridian Altitude below the Pole.

To set the sextant for an observation on the meridian below the pole, subtract the star's polar distance from the latitude by dead reckoning, which will give the approximate altitude.

From what has been said, it will be apparent that to find the time of a star's transit below the pole on any particular day, it is only necessary to add 11 hours 58 minutes to the time of upper transit given in Raper's Table. The following lists comprise useful circumpolar stars in both hemispheres.

The observer being to the northward of 49° North latitude, the undermentioned are available:—

Northern circumpolar stars.

				H.	M.
Schedar, (α *Cassiop.*)	mag.	2·2 to 2·8	—Right Ascen.	0	35
Mirfack, (α *Persei*)	„	1·9	„	3	17
Dubhe, (α *Ursæ Majoris*)	„	2·0	„	10	57
Phecda, (γ *Ursæ Majoris*)	„	2·6	„	11	48
Benetnasch, (η *Ursæ Majoris*)	„	2·0	„	13	43
Kochab, (β *Ursæ Minoris*)	„	2·1	„	14	51
Etanin, (γ *Draconis*)	„	2·4	„	17	54
Alderamin, (α *Cephei*)	„	2·6	„	21	16

ALDERAMIN (α Cephei).

Alderamin lies well on towards midway on a perfectly straight line joining *Vega* with δ Cassiopeiæ: the latter is the star at the bottom of the left leg of the W.

North of 51° North latitude, the following may be added to the list:—

				H.	M.
Capella, (*α Aurigæ*)	mag.	0·2	—Right Ascen.	5	9
Deneb or Arided, (*α Cygni*)	„	1·5	„	20	38

In high Southern latitudes, observations below the pole are of greater utility than with us in the more favoured hemisphere, where the Pole star is on duty all through the night. It is a thousand pities that the Southern celestial pole is not furnished with as efficient a sentinel. Truly, *σ Octantis* is only 0¾° from the pole, but being a star of the 6th mag. it is useless to seamen. It is, however, some consolation that the Pole is surrounded by half a dozen other stars, mostly of great brilliancy, which, if not quite so ready to hand, go far to make up the deficiency, as indicated below.

Southern circumpolar stars.

				H.	M.	Available to the Southward of	°	
Achernar, (*α Eridani*)	mag.	1·0	—R.A.	1	34		42	S.
Canopus, (*α Argûs*)	„	−0·4	„	6	22	„	47¼	S.
———, (*α*[1] *Crucis*)	„	1·3	„	12	21	„	38	S.
———, (*β Centauri*)	„	1·2	„	13	56	„	40½	S.
———, (*α Centauri*)	„	0·7	„	14	32	„	40	S.
———, (*α Pavonis*)	„	2·1	„	20	17	„	43	S.

The star σ Octantis is almost midway on a line joining Achernar and β Centauri. The two latter are therefore on opposite sides of, and practically equi-distant from, the pole. Consequently, when Achernar is on the meridian *above* the pole, β Centauri—roughly speaking—is on the meridian *below* the pole, and *vice versâ.*

Stars which do not set to the observer lie within what is called the Circle of Perpetual Apparition, and are distinguished as *Circumpolar* stars. On the other hand, those stars which do not rise above his horizon lie within the Circle of Perpetual Occultation. When the observer is on the Equator both these circles disappear. Heavenly bodies—of whatever declination—will there rise and set vertically, and their diurnal circles will be bisected by the horizon, so that they will be 12 hrs. above it and 12 below: hence day and night are equal. The Celestial Equator will pass vertically overhead through the zenith, and the Poles will be in the horizon.

Remember that the altitude of the Pole is equal to the Latitude of the observer, consequently, if the former is 0° the latter must also be 0°.

CHAPTER V.

LATITUDE BY THE NORTH STAR (POLARIS).

The constellations of the Great and Little Bears are so very important that they deserve a chapter to themselves. The student of the heavens should begin by making himself thoroughly acquainted with them as starting points in search of the remainder.

The 'Great Bear.'

The 'Great Bear' is very conspicuous; and the figure formed by the seven principal stars is variously termed—the Plough, the Skillet, the Cleaver, the Dipper, the Waggon, and Charles's Wain.

The star at the extremity of the tail (or handle of the 'Plough') is named BENETNASCH. The two at the opposite, or leading end, of the 'Plough' are termed the "POINTERS," because a line through them, if produced, will pass close to the North star. This, by the way, is the best means of finding it. Of these two, the one nearer the North Star is known as DUBHE, the other as MERAK.

The 'Pointers.

The 'Little Bear.'

With the exception of the 'Pole Star,' and the 'Guards,' those in the 'Little Bear' are faint, and at times somewhat difficult to make out. Altogether the 'Little Bear' plays second fiddle to its relative. The one redeeming feature is that it can boast of the North Star.

There are points of similarity and dissimilarity between the two Bears. Each has seven principal stars: four of them form an irregular square, and the remainder a tail. The dissimilarity consists in the tails having opposite curvatures; that of the 'Great Bear' droops, whilst the other turns up. Again, the figures are different as regards size; and lastly, the magnitudes in the one case are fairly uniform as compared with the poverty of the bulk of them in the other.

'Polaris' is in the extremity of the tail of the Little Bear, just as Benetnasch is in the extremity of the tail of the Great Bear.

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The "Pointers" in the latter correspond to the "Guards" in the former.

The two middle stars in the tail of the 'Plough' face the 'Guards,' the four forming a narrow oblong, with *Thuban* (α Draconis) lying midway as a sort of faint connecting link between the two constellations.

About 2300 B.C. *Thuban* was the Pole star, and barely $\frac{1}{4}°$ distant from the pole. There is reason to believe that *Thuban* was then somewhat brighter than at present.

The North star—particularly useful for finding the latitude.

The North star (Polaris) is particularly accommodating in affording seamen a ready means of determining the latitude at any hour of the night. This invaluable guide is now a degree and a quarter ($1\frac{1}{4}°$) distant from the Pole of the heavens; and as the diameter of its diurnal circle ($2\frac{1}{2}°$) is small in consequence, the star's apparent revolution round the Pole is very slow, being only about a minute of arc (1′) in three minutes of time. This enables observations for latitude to be made regardless of whether the star is on or off the meridian, as an error in the time used in the computation—unless very considerable—has but little effect on the result.

Did the North star but occupy the exact position of the Pole, it would be a fixed point, and its altitude, when corrected for instrumental error, dip, and refraction, would give the latitude of the observer without any calculation whatever. This is fully explained on pages 366—367.

Vega the future Pole Star.

At present the Pole is approaching the North star, and in a century or thereabouts will have reached within half a degree of it, when it will commence to recede, and gradually come nearer to the bright star *Vega*, which, in about 12,000 years—owing to what is known as the *Precession of the Equinoxes*—will then become the Pole star.

How to find the North Pole of the heavens.

The imaginary point representing the Pole of the heavens may be found by drawing a line from ζ Ursæ Majoris (the middle star in the tail) to within a degree and a quarter of the North star. These two stars are consequently on diametrically opposite sides of the Pole. When ζ Ursæ Majoris is six hours from the meridian, the North star will be also, and its altitude in that position will be nearly the same as the elevation of the Pole. It will be known when this is the case by a line through ζ Ursæ Majoris and Polaris being parallel with the horizon. The eye can guess this pretty accurately. (*See* Plate facing next page.)

How to know when Pole star has same elevation as the Pole.

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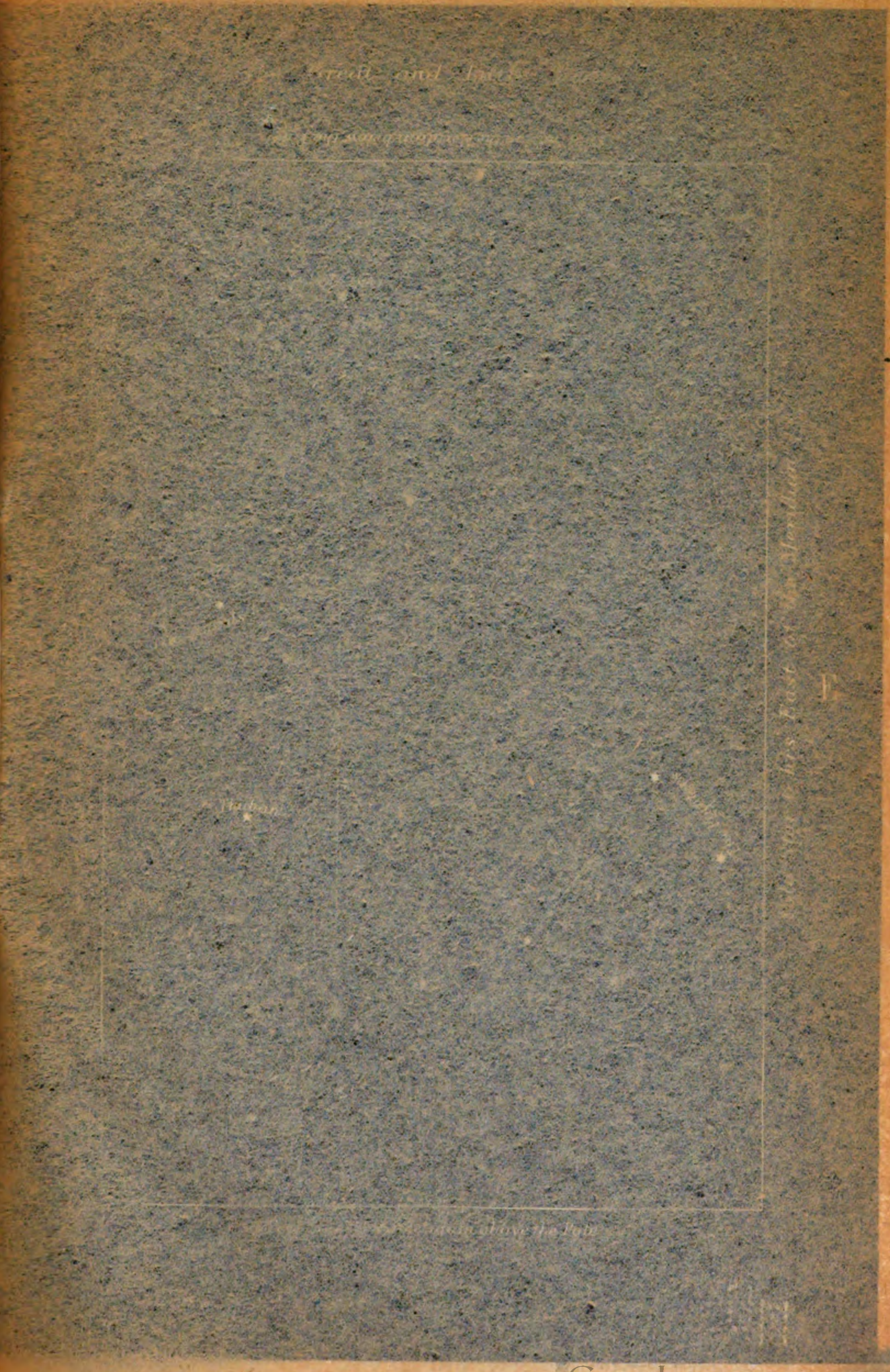

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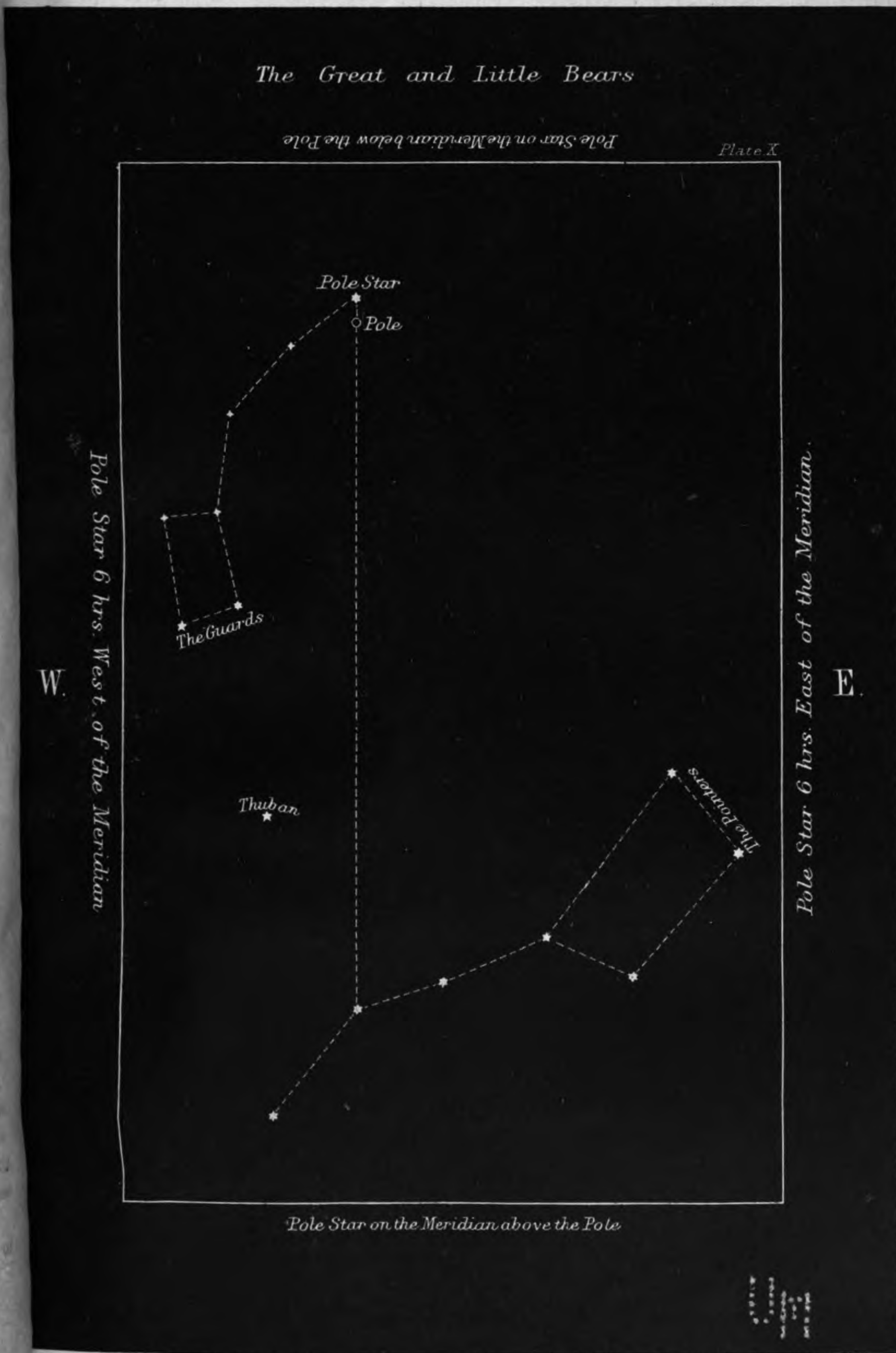

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Raper, will give a rough shot at the Latitude. This is mentioned, not to advocate such a slap-dash mode of finding it, but to exhibit the principle.

As a matter of fact—for an *accurate* determination—the Pole star is then in its worst possible position, as at such times its vertical motion is most rapid, and an error in the time produces its greatest effect, namely, 1′ of latitude for every three minutes of error in the time. On the other hand, when the Pole star is near the meridian either above or below the pole, its motion in altitude is least, and an error in the time is of little or no consequence. Reference to Table 51 of Raper will shew that for half an hour on either side of the meridian the altitude will barely change 1′, so that the observer has ample time to get a good sight without being embarrassed by the rising or falling of the star. This, then, is the best time for observing.

Best time for observing Pole star.

The time of transit may be found by consulting Table 27 of Raper, or by the appearance of the Great and Little Bear. When ζ Ursæ Majoris (sometimes called *Mizar*) is vertically above or below Polaris, the North star will be on or near the meridian. This is shewn in the diagram. Any trifling weight—such as a stone or a marline-spike—slung to half a fathom of seaming twine and held at arm's length towards the stars, will materially assist the untrained eye in judging the vertical. Similarly, in getting a line of direction between stars in other positions, it is a good plan to take them "out of winding" with a straight-edge, especially when far apart. The writer found this of great service through many a long winter's night when concocting Chapter II. on "Sky Pilotage."

How to know best time for observing.

When Spica is on the meridian so is Polaris; the one above, and the other below, the pole. (*Vide* Table 27 of Raper).

β and γ in the Little Bear are called the "Guards:" *Kochab* (β) is rather the brighter of the two.

There are two ways of working out the latitude by Polaris; one is known as the *Nautical Almanac*, and the other as the *Epitome*, method. (Raper, Table 51). The former is the more exact, and as the difference in the length of the calculation is so trifling as not to be worth speaking about, the preference is given to it, especially since it possesses the decided advantage of familiarizing the navigator with Sidereal Time in the precise form employed in certain of the stellar problems herein treated of. *Therefore, mark well how it is arrived at.* It is a matter of importance, in the first place, to select a good form of working,

Latitude by Pole star—two methods.

and then to stick to it. This has been made a leading feature in "Wrinkles."

EXAMPLE.

At about 8·10 P.M., May 19th, 1880, when in Latitude and Longitude by account 41° 47′ N. and 55° 45′ W., observed the altitude of star Polaris to be 40° 36¾′, when a chronometer which was 3m. 56s. slow of G.M.T. shewed 11h. 41m. 31s. P.M. same date. Eye 32 feet. Index error + 45″. No arc errors.

Nautical Almanac method.

	H.	M.	S.	
	11	41	31	Time by chronometer.
+		3	56	Error of chronometer.
	11	45	27	G.M.T.
−	3	43	00	Longitude in time W.
	8	2	27	Mean time at ship.
+	3	50	8	Sid. time at Greenwich mean noon.
+		1	56	Acceleration for 11h. 45m. 27s.
	11	54	31	Sidereal time of observation at ship, or, in other words, the Right Ascension of the Meridian of observer.

		°	′
Observed alt. of Polaris		40	36¾
Index error	+		¾
		40	37½
Correction, Table 38 of Raper ..	—		6½
True altitude		40	31
Constant correction	−		1
Reduced altitude		40	30
1st corr. Table I. N.A., page 483	+	1	15¼
2nd corr. Table II. N.A., page 484		0	00
3rd corr. Table III. N.A., page 484	+		1
Latitude		41°	46¼′ N.

This looks formidable on account of the explanatory writing at the sides, which is inserted as a guide to the learner; but in actual practice most of this is omitted, and the figures themselves are not many.

In the N.A. method (*vide* above example) there is a *constant* correction of 1′ subtractive; and as the question has often been asked *why* the true altitude should *always be diminished* by this amount without any apparent reason, the explanation is now given:—In the construction of Table II. the Polar Distance and Right Ascension of the North Star are assumed to be invariable throughout the year, but this is not the case, as may be seen by turning back to the Table on pages 308–315 of the *N.A.* for 1895.

Mathematical juggling exposed.

Table III., which is an auxiliary to Table II., depends on the *difference* between the *true* and *assumed* values of the P.D. and R.A., and contains the necessary correction, *increased by* 1′ for the sake of rendering the quantities *always* additive; and as it would not do to allow this convenient unit to remain to vitiate the result, it is quietly got rid of near the beginning of the problem.

Some slight allusion has been made in this and previous chapters to the phenomenon known as *Precession of the Equinoxes.* This is a matter which pertains more to Nautical Astronomy than to Practical Navigation, but as these two are closely allied, and Precession is constantly cropping up in connection with one or other of them, the author thinks no apology is needed to introduce it more particularly to the notice of the reader. Moreover, it is much more satisfactory to understand it than not to understand it, especially when ten minutes will suffice for the purpose.

The following—by kind permission of the publishers of *Chambers's Journal*—is copied *verbatim* from the March number for 1885. It is selected from among many articles by various writers as being at once a clear, concise and popular explanation, such as will be likely to recommend itself to the favour of intelligent seamen.

WHEN SHALL WE LOSE OUR POLE STAR?

"This may be to some of our readers a startling question; for most of us have had that star pointed out to us many years; and perhaps those who directed our eyes to it little thought that there would ever be any other pole-star. Precession of the Equinoxes

"It is well known that if the northern extremity of the axis of our earth were lengthened until it met the imaginary sphere of the heavens, it would come very near to our present pole-star, hence called Polaris; and if, for any cause, the direction of that axis were materially altered, that star would no longer be a true index of the north. Prolongation of earth's axis

"We now propose to show that such a change of the direction of the earth's axis is continually taking place; and that the terrestrial axis when thus lengthened describes a cone, the apex of which is the centre of the earth; and the circumference of the base of the cone is a circle described amongst the stars. When the axis has described one-half of its course, the angle between the two positions it occupies at the beginning and at the middle of the rotation is about forty-seven degrees. And thus the extremity of the axis will successively come near to other stars than our present pole-star; and in about twelve thousand years it will have as the Polaris the very conspicuous star Vega, or α in the constellation Lyra. Constant change in 'pointing' of axis.

"We now proceed to explain the reason of this movement of the earth's axis. It is well known that the earth is not a perfect sphere, but is flattened at the poles, being what astronomers call an oblate spheroid. Now, the sun's attraction upon such a spheroidal body is not quite the same as it would be upon a perfect sphere. When the sun is at either equinox—that is, just over the equator—the attraction exercised upon our earth is the

Variability of sun and moon's attraction.

same as if that body were spherical; but when the sun is at or near the upper tropic, its action upon the terrestrial matter which bulges at the equator has a tendency to pull that matter towards the ecliptic, and to make the axis of the earth approach to a vertical to the ecliptic. The same influence is at work when the sun is near the lower tropic. And if this influence were not counteracted, the effect would be to cause the ecliptic and equator ultimately to coincide; and our annual succession of seasons would be done away with. But as no such catastrophe is threatening us, and the inclination of the ecliptic to the equator remains about twenty-three and a half degrees, there must be some force which neutralises the above tendency: this is the rotation of the earth on its own axis. No one but a good mathematician could *a priori* tell the exact effect of these two forces combined.

Why a pegtop spins without falling.

But any one may see how rotation may affect the motion of a body acted on by another force, by observing how a pegtop is kept upright by the rotation, whilst it falls as the rotation ceases. The influence of this rotation to keep a body from falling may be noticed by anyone who carefully observes a spinning coin when about to fall. While the coin spins rapidly, its uppermost part appears as a point. As it falls, the point becomes a small circle, increasing as the rotation slackens. But if the coin be very closely watched, when beginning to fall, it will be seen that the small circle is for a moment diminished, showing that the coin had partially recovered its upright position. This recovery is entirely due to the rotation.

"Similarly, a bicycle is kept from falling by its horizontal motion; and a conical bullet, which has gained a great rapidity of rotation from a rifled barrel, keeps the direction of its axis without deflection to the right or left. And thus we find that the present position of the earth's axis with respect to the ecliptic is not altered; but the two forces acting upon the earth cause the axis to rotate, as above described, so that the north pole describes a circle in the heavens.

"But as the period of this rotation is very great, it was not easy to detect such a result, except after a long period of observation. It was discovered thus. The point where the ecliptic and equator cut is called the first point of the constellation Aries, one of the well-known twelve signs of the zodiac. From this point all celestial measurements are made eastwards. Each star of importance has had its distance east of that point—called its right ascension—recorded. In the course of time, the tables of these numbers so recorded appeared to be erroneous; but the error was so regular, and all in one direction, that it was conjectured that the point from which these right ascensions were reckoned had itself shifted its place. And so it proved; and if anyone looks at a celestial globe, he will see that Aries no longer occupies the position where the equinox is, but is somewhat to the east, or right, because the point of intersection of the ecliptic and equator has slipped back. But as the sun appears to take a shorter time to come back to the equinox than to arrive at the same stars, which were once close to that point of intersection, this slow retrograde motion is termed the *precession* of the equinoxes. **Right Ascensions—whence measured.**

"The distance on the equator caused by this retrograde motion would, if not otherwise modified, be 50″·41 annually. But the attraction of the planets on each other produces a very small motion of the equinox in the other direction; and so the resulting precession is about 50″·1 annually. If we divide the three hundred and sixty degrees of the circle by the above small quantity, we shall find that the period of the revolution of the earth's axis is 25,868 years. **Annual amount of Precession.**

"Of course the moon has an influence on the extra mass at the earth's equator, as the sun has, similar in kind, but far less in quantity. This influence would cause the earth's axis to describe very small cones of the same nature as the large cone above described; and the period of every rotation would be about nineteen years. The effect of this second or lunar influence is to cause the earth's axis to dip a little towards the equator, and then to resume its position; and this nodding motion is termed *nutation*, from the Latin word *nutare*, to nod. Thus the axis of the earth describes a cone not of uniform surface, but as it were fluted, and completes its majestic round in nearly twenty-six thousand years, pointing to a various succession of stars which will in their turns be honoured by future astronomers as the pole-stars of their respective generations." **Nutation.**

It is curious that no mention is made in the above description of a philosophical toy (procurable for a few shillings), known as the *Gyroscope*, the principle of which has now been satisfactorily applied to compasses.* **The Gyroscope.**

This little apparatus illustrates the surprising properties of both simple and compound rotation. Its very peculiar action

* See Appendix S.

depends upon the law that if a mass be set revolving about its principal axis of inertia of greatest or least moment, the direction of the axis will remain absolutely unchanged, *so long as the rotation continues unimpaired and extraneous force is not applied.*

Universal gravitation.

This is precisely the position of our earth. Rotation would keep the polar axis fixed in space—always pointing to the same star—were it not for the disturbance caused by the attraction of other neighbouring bodies.

CHAPTER VI.

LATITUDE BY EX-MERIDIAN ALTITUDE OF THE SUN.

Many are now the methods of working 'Ex-meridians,' all more or less good in their way. The author's prime favourite in days gone by was Towson's, which has many good points to recommend it—among others, its independence of the latitude by account; but as relentless Time rolls on, one thing supersedes another, and the difficulty—daily increasing—is how to keep pace with this ceaseless movement, and how to find time for the investigations necessary to separate the residuum of wheat from the preponderating bulk of chaff.

Towson's Tables surpassed

Twenty-seven years ago stars were not so much to the front as they are now, so Towson's Tables did not extend beyond 23° 20′ of declination, which means that at length they have to give way to others of greater scope. The same may be said of Bairnson's—otherwise excellent.

A handy method in very small compass is due to Captain James Smith, and is published by H. Hughes and Son of Fenchurch Street. These very concise Tables run to 60° of Latitude, and the same of Declination; they consequently embrace a big area, and in that respect are an advance upon both Towson and Bairnson. Admirable though they be, the writer nevertheless prefers those of Messrs. Brent, Walter, and Williams, which came out in 1886.* These latter extend to 60° of Latitude and 70° of Declination. Like the others already mentioned, the method is short, sure, and simple, but this one is the *ne plus ultra*.

Smith's and Bairnson's Tables.

Brent's Tables the most comprehensive.

Their book also includes an explanation of that phase of the Sumner or Double Altitude problem now known as the "New Navigation." This the reader can take or leave as he pleases. Whilst admitting its neatness, the writer is averse to the diagram part of the method, which somehow seems to him out of place in

The 'New Navigation

* London: George Philip & Son, Limited, 32 Fleet Street, London.

a ship, except perhaps in fine weather with the advantage of a commodious chart-room, and this latter is unfortunately not always to be had in the mercantile marine. The "New Navigation," however, has ceased to be of the "fancy" type, and its utility is being increasingly demonstrated in practical work at sea from day to day.

But we are digressing, and must hark back to Ex-meridians.

When the sky is cloudy, the sun or other celestial body, though it may happen to be obscured so that the *meridian* altitude is unattainable, nevertheless frequently appears for short intervals both before and after its meridian passage. If not observed at these times, the Latitude may be lost for the day; and as the finding of the Longitude is generally dependent upon a correct knowledge of the Latitude, the morning sights will have been taken to little purpose.

Advantages of Ex-meridians.

In addition to the extreme simplicity of the Ex-meridian problem, it has this to recommend it,—that neither is the patience taxed, the eye fatigued, nor the instrument unnecessarily exposed by the usual weary waiting for the Meridian altitude, as *one* observation within the prescribed limits suffices for the correct determination of the Latitude, if the Apparent Time at Ship be known with tolerable accuracy. Were it not indeed, that the wide application of this most useful problem is somewhat restricted, it would deserve to rank *before* that of the Meridian altitude, which latter—since the introduction of easy solutions of the Ex-meridian problem—is certainly no longer of the same importance.

Application limited in low latitudes.

If the value of the problem under consideration be somewhat lessened owing to its unsuitability in low latitudes, it must not be forgotten that in such regions there is generally but little difficulty in getting the sun exactly at noon, so that the inapplicability of the method at such times is not much felt.

Rule regulating Hour-Angle.

The rule regulating the limits within which Ex-meridians may be taken is easily remembered, namely—*The hour angle of the sun, or time from noon, should not exceed the number of degrees in the sun's* MERIDIAN *zenith distance.* Therefore, if the sun's *meridian* altitude be about 80°, the time from noon of an Ex-meridian observation should be less than ten minutes. In Towson's method, the Tables admit of a 20 minutes hour angle even with an altitude of 74°, beyond which it is not prudent to go, as the results would be doubtful.

The correctness of the Latitude deduced from the method of reduction to the meridian, depends upon the accuracy with which the Apparent Time at Ship is known, *and the higher the altitude the greater is the precision required in the time.* If sights have been taken *at a suitable hour* in the morning (see chapter on Longitude by Chronometer), there should be no hitch on this account. But admitting the Apparent Time to be in error somewhat, there is still a way of circumventing the difficulty. *Get a P.M. Ex-meridian as well as an A.M. one, and endeavour that both shall have about the same altitude.* The *mean* of the two resulting latitudes—*after each has been reduced to noon*—will be within a fraction of the truth. In a note Towson says:— **Dodge when Hour Angle is faulty.**

"If equal altitudes be taken before and after the meridian passage, half the elapsed time may be employed as the hour angle for determining the reduction. Or, when the altitudes before and after noon differ by only a few minutes,* the mean of the two may be reduced by employing half the elapsed time as the hour angle for reducing the mean altitude." **Towson's dodge.**

In these rules no allowance is made for observer's change of position; and though they may be sufficiently accurate in a slow moving vessel when the hour angle is small, or where the course is nearly East or West, they would scarcely do in a fast steamer, steering North or South with a large hour angle. So if these rules should at any time be employed, care must be taken to see that the circumstances are not objectionable. **Results affected by ship's change of position.**

There is yet another dodge, when the time is uncertain, by which it may be approximately corrected. If two *equally good* Ex-meridian altitudes, with an interval between them of say ten minutes, be taken on the same side of noon; and the second latitude, on being worked back to the place of the first by allowing the correction due to the course and distance in the interval, does not agree with it, the Time is probably in error; in which case the *mean* latitude is *not* to be taken as the true latitude, *from the fact that an error in the time affects least the observation nearest the meridian;* which latter is accordingly to be preferred. It will be easy then to find *by trial* the hour angle which will make the first result agree with the last; and thus the Apparent Time may be *approximately* corrected. **Mode of approximately correcting Hour Angle**

It is unnecessary in these pages to give the *rule* for working 'Ex-meridians,' according to Brent, Walter, and Williams, but *examples* are given in this and Chapter VIII. to afford an opportunity of complying with the adage—

* Minutes of arc (′) are of course meant.

"Taste and try
Before you buy."

The Apparent Time at Ship is deduced from the chronometer time in the manner already explained in the chapter about Azimuths.

EXAMPLE.

November 18th, 1881, about seven bells in the forenoon, in Latitude by account 51° N., and Longitude 11° 30′ W., the observed altitude of the sun's lower limb was 19° 20½′ S., when a chronometer which was 4m. slow of G.M.T. shewed 0h. 2m. 30s. P.M. same date. Eye 24 feet. Required the latitude at instant of observation, *and also at noon;* the ship making S. 14° W. (true), 14 knots.

	h.	m.	s.
Time by Chronometer	0	2	30
Error slow	+	4	0
G. M. T.	0	6	30
Equation of time	+	14	36
G. A. T.	0	21	6
Longitude in time W.	—	46	0
Westerly Hour Angle	23	35	6
Easterly Hour Angle	0	24	54

	°	′	″
Sun's observed altitude	19	20	30
Correction—Table I.	+	8	48
Sun's true altitude	19	29	18
*C. 1·	+	10	25
·2		2	5
·03			19
Meridian Alt. at place of obs.	19	42	7
	90		
Mer. Zen. Dist. at place of obs.	70	17	53 N.
Corrected declination	19	20	43 S.
Lat. at instant of observation	50	57	10 N.
Correction for Run till noon	—	5	30 S.
Latitude at noon	50	51	40 N.

Ex-meridian gives latitude at time of observation.

It is *very* important to understand that the above meridian zenith distance, 70° 18′, was the sun's actual meridian zenith distance *at the place where the altitude was taken;* and the resulting latitude, 50° 57¼′ N., *was the latitude of the ship at the time of the observation* (*not* at noon). *Therefore, always bear in mind that the Latitude found by an Ex-meridian altitude is the Latitude of the ship at the instant of observation, and if afterwards you should require to know what it is at noon, you must correct it by the difference of latitude (out of the traverse tables) due to the course and distance which the ship has made in the interval.*

Common misconception.

Ignorance of this has been a fruitful source of error with *many* seamen of the writer's acquaintance, who, until it was fully ex-

* Entering Table III., with latitude by account 51° N., and declination 19° 30′ S. (contrary names) gives C 1″·23.

From Table IV., with Hour Angle 25m. 0s. and C 1″·23, we obtain the above correction.

plained to them, were inclined to dispute the truth of the above statements. It is easy to see that, in a case similar to the imaginary one pictured on pages 368—369, if the latitude were found by an "Ex-merid.," instead of the meridian altitude, *and if the reduction to noon were not made*, a like catastrophe might well ensue.

Reduction to noon.

In working 'Ex-meridians' it might be useful to know approximately what error would be produced in the resulting latitude by an assumed error in the Hour Angle. As the formula is short, it can readily be employed when the observer has any doubt as to the suitability of the selected object. It is necessary that the true azimuth should be known, and this can be found as most convenient.

Test of suitability

Rule:—Add together the cosine of the Lat., the sine of the Bearing, and the log. of the assumed error in the Hour Angle (expressed in arc). The natural number corresponding to the log. of the sum will be the error in the Latitude.

PREVIOUS EXAMPLE.

Latitude 51° N..	Cosine	9·7989
☉ True Bearing, S. 6° 15′ E.	Sine	9·0369
Assumed Error = 1^m = 15′	Log.	1·1761
1′·03 =	Log.	0·0119
60		

Error in Lat. for an assumed error of 1^m in the Hour Angle...... } = 1′ 1″·80, say 1′ 2″

CHAPTER VII.

TIME.

Before going any deeper into the various star problems which are considered of practical value, it is as well that the reader should be thoroughly at home in the subject of *Time*—especially *Sidereal Time*. The word *Sidereal* means—of or belonging to the stars, and is derived from the Latin *Sidus*, a star.

By the generic term *Day*, is meant the interval of time between the departure of a heavenly body from any meridian and its next return to it. It derives its distinguishing name from the particular body referred to: thus we have a Solar day, a Lunar day, and a Sidereal day.

Sidereal day.

A *Sidereal day* is the period in which the earth performs one complete revolution round its axis, and, setting fractions on one side, is equal to 23h. 56m. 4s. of *mean time*, as measured by our clocks or watches; so that the common expression, that the world revolves once in twenty-four hours, is incorrect, unless *Sidereal* hours are either specified or understood.*

Earth's yearly rotation.

The earth really rotates on its axis 366 times in the course of a year; but as we also make one revolution round the sun in the same period, the sun appears to travel round us only 365 times.†

A *Sidereal day* is shorter than a *mean Solar day* by 3m. 56s.; consequently, the stars come to the meridian of any place nearly four minutes of clock time *earlier* on each succeeding day. Their

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* The interval occupied by the earth in performing one revolution round its axis is taken as the *standard* for the measurement of time. The velocity of rotation is considered never to vary in the slightest degree; but Lord Kelvin supposes, from certain mathematical investigations made by him, that this may not be altogether true. These investigations lead him to believe in the possibility of the earth's motion being infinitesimally retarded by the tidal wave, which, moving in the opposite direction, acts upon it after the manner of a friction brake. From the impossibility at present of constructing clocks to go with sufficient regularity, there is no direct way of testing this idea.

† In the language of nautical astronomy, the earth (for sake of convenience) is considered as standing still, and the heavens to be moving round it.

revolution in the heavens may be taken as perfectly regular, since our distance from the stars is so inconceivably great, that the earth's annual motion in space is quite imperceptible when compared with it.* With the sun it is otherwise. Owing to the non-coincidence of the Equator with the Ecliptic, and the unequal motion of the sun in the latter,† due to the eccentricity of the earth's orbit, the solar days are of varying length. The period between two successive transits of the sun is known as an *Apparent Solar Day;* but, from its irregularity, it would be impossible to get clocks which would conform with it, so as always to point to 12 when the sun was on the meridian.

Daily revolution of stars perfectly regular.

Solar days vary in length.

To get over this and other difficulties, astronomers conceived the idea of creating an *imaginary sun*—which, like the stars, would be uniform in its motion. The interval between two successive transits of this imaginary sun is termed a *Mean Solar Day, and is equal to the mean or average of all the Apparent Solar Days in a year.* It is this to which our clocks and chronometers are adjusted, as well for navigational as the every-day purposes of life; but, in observatories, it is also customary to have an additional clock regulated to *Sidereal time*, on account of its greater convenience in connection with certain of the astronomical observations. The dial of this clock is numbered up to 24 hours, so that the short hand makes but one round of the circle in the day.‡

Imaginary or Mean Sun moves in the Celestial Equator.

Sidereal clock face—how marked.

The difference between apparent and mean time at any instant, or the angle at the pole, or the arc of the equinoctial, between the circles of declination of the real and imaginary suns, expressed in time, is familiarly known to sailors as the *Equation of Time.* Sometimes the imaginary sun is ahead of the real one, and sometimes it is astern of it, according to the period of the year. The fact as to which of the two is leading decides the application of the equation of time, as set forth in the precept at the head of its column in the *Nautical Almanac.*

Equation of Time.

A sun dial shews *Apparent* time, and consequently its indications will only agree with *Mean* or clock time when the real and imaginary sun happen to coincide, or pass the meridian at the same instant. This actually occurs four times in a twelvemonth, namely, about April 14th, June 13th, August 31st, and December 23rd. Accordingly, on these days—at a particular moment—the Equation of Time is *nil.* The dates vary slightly from year to year.

Apparent Time, and difference between Sun-dial and Clock Time.

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* See pages 320—321. † See footnote on page 368.

‡ In parenthesis, let it be here remarked, that chronometers for use on ship-board should have their faces figured in a similar manner. Were it so, it would save many mistakes.

The foregoing explanations ought to make clear the meaning of the terms *Apparent Solar day* (apparent time), *Mean Solar day* (mean time), and *Sidereal day* (sidereal time). Until the reader feels that he perfectly comprehends them he had better not attempt to go further.

Mean Time.

Mean time begins (that is, a mean solar clock points to 0h. 0m. 0s.) at *mean noon;* or what is the same thing—at the instant of the passage of the *imaginary* sun across the meridian.

Sidereal Time.

Sidereal time begins (that is, a sidereal clock points to 0h. 0m. 0s.) when the first point of *Aries* is on the meridian of the observer, and is counted straight through 24 hours till the same point returns again. The hour angle or meridian distance of this point is accordingly *Sidereal time.*

First point of Aries.

It is now necessary to know what is meant by the first point of *Aries.* It is that point in the heavens which the sun's centre occupies at the *Vernal equinox* when its declination changes from South to North; or, as sailors say, when the sun *crosses the Line* bound North.

This point, like the mean sun, is purely an imaginary one, as nothing exists to mark its place, nor would it be any particular advantage were it otherwise; moreover, the point itself is liable to a certain slow movement westward,—so slow, however, as not to affect perceptibly the interval of any two of its successive returns to the meridian, although in a year the amount of retrogression (50"), as it is called, is quite appreciable.

On the other hand, at the autumnal equinox, when "Old Jamaica" bids good-bye for a spell to this hemisphere, the position of his centre marks the first point of *Libra.* From what has been said it will be seen that these two 'Points' represent the intersections of the Celestial Equator with the Ecliptic. When the sun is in either of these positions, day and night are of equal length all over the world.

Precession discovered by Hipparchus.

But here it must be explained that the actual equinoctial points no longer occupy the same place in the heavens that they did 2000 years ago, when the famous Greek astronomer Hipparchus discovered *Precession.* At that time they happened to coincide with *Aries* and *Libra* respectively, and were dubbed accordingly; but, as already stated, inexorable *Precession* has caused these points, one of which Hipparchus took as his zero, to retreat westward along the Ecliptic at the annual rate of 50", so that now, except in name, they find themselves cut adrift from Aries and Libra, and respectively about to leave the constellations *Pisces* and *Virgo* for *Aquarius* and *Leo,* or fully 30° from the starting point of Hipparchus.

The retreat of the equinoctial points through the constellations of the zodiac will go on slowly but surely till the complete tour of the heavens shall have been made. This will require a period of 25,868 years; meanwhile, we will continue to talk of the *imaginary* 'first point of Aries' as distinct from the *real* 'first point of Aries,' and thus breed confusion, unless an Act of Parliament should decree something more rational.

The "signs" and constellations of the Zodiac part company.

It is from this peripatetic point as zero that the *Right Ascensions* of all celestial bodies are measured. The *Right Ascension and Declination of a point in the heavens correspond to the Longitude and Latitude of a station on the earth.*

Equivalents of Right Ascension and Declination.

Right Ascension, which we come across so frequently in Nautical Astronomy, may be defined as an arc of the equator included between the aforesaid imaginary first point, or commencement, of *Aries* and the celestial meridian of the body it refers to, and is reckoned on the *celestial* equator exactly as the *Longitude* of places on the earth is reckoned on *our* equator; with this distinction, however, that *Right Ascension is reckoned continuously through 24 hours from west to east,* or in the opposite direction to the apparent diurnal motion of the heavenly bodies,—whereas *Longitude* is counted as east *or* west of Greenwich, or any other arbitrary meridian, such as Paris, or Cadiz, according to caprice. Moreover, as the stars do not preserve that constant position with respect to the meridian which they do with respect to the equator, there cannot be that correspondence between *Right Ascension* and *Longitude* which *does* exist between *Declination* and *Latitude.*

Definition of Right Ascension.

This being understood, we next come to the term *Hour angle,* or *Meridian distance* as it is sometimes called. It may be defined as the angle at the Pole, included between the meridian of the observer and the celestial meridian of the body referred to. Like the *Right Ascension,* the *Hour angle* is measured on the *celestial* equator in the same way that *Longitude* is measured on the *terrestrial* equator.*

Definition of Hour Angle.

In turning these definitions over in the mind, one must try not to get "mixed," as will, however, very likely be the case with those whose attention has only been seriously called to them now for the first time. Do not be disheartened and tempted to skip, but try back, and each fresh reading will give more insight, until the whole is as plain as *A B C.* Often it is a good plan to

"Time"—a difficult study.

* It must not be forgotten that longitude is reckoned in *time* as well as in *arc.*

sleep on a matter difficult to understand, and attack it again in the morning when the brain is vigorous.

Time is an essential element in navigation, and, entering as it does into all of the astronomical problems, is as necessary to be understood as the points of the compass. Unfortunately there is no "royal road" to these more abstruse questions—nothing for it but to hammer away at them with all possible concentration of thought till the victory is gained.

Equality in differences of Longitude and Right Ascension.

If the reader has got a clear conception of the foregoing, he will scarcely require to be told that the *Hour angle* of the first point of *Aries* is equal to the *Right Ascension of the Meridian* of an observer, which again is precisely the same thing as *Sidereal Time.* From this it follows that *difference* of *Right Ascension* may with perfect propriety be considered *as a portion of Sidereal time, or as Longitude.*

Thus, if a certain star were on the meridian of any place—say New York—at the same instant that another star was on the meridian of Greenwich, the *difference* of the *Right Ascensions* of these two stars would be equal to the Longitude of New York.

Time Problems

By turning to page II. for the month in the *Nautical Almanac*, it will be found that the last or right-hand column is headed "SIDEREAL TIME." In the words of the explanation given on page 501 of the N. A. for 1895, this "SIDEREAL TIME" "is the angular distance* of the first point of *Aries*, or the true vernal equinox from the meridian† at the instant of Mean noon. It is, therefore, the Right Ascension of the Mean sun, or the time shewn by a sidereal clock at Greenwich, when the mean time clock indicates 0h. 0m. 0s." In proof of this it will be noticed on the same page that the *Equation of Time* is equal to the difference between the *Apparent Right Ascension* of the sun at Mean noon, and the *Sidereal time* at Mean noon.

By the foregoing, it ought to be again made evident that *Sidereal time* and *Right Ascension of the meridian* are one and the same thing. Now, since the measure of *Sidereal time* is identical with the measure of Longitude, if by any means we can know the *Sidereal time at Greenwich* corresponding to the *Sidereal time at Ship*, we have at once the Longitude of the ship as measured from Greenwich.

In the thoughtful mind the question may be raised as to whether Longitude, when measured by an interval of *Sidereal*

* Reckoned in *time* not in *arc*. † At Greenwich.

time, is the same as when measured (numerically speaking) by a similar interval of *Mean* time, seeing that sidereal and mean time have different absolute values. Raper, in a foot-note,* disposes of this question thus:— **Similarity of Sidereal and Mean Time intervals.**

"The diff. long. is found as well by means of the motion of a star as of the sun; that is, by means of a clock or chronometer regulated to Sidereal time, as well as by one regulated to Mean time. For although the absolute interval of time employed by a star in moving from one meridian to the other is less than that employed by the sun, yet it is divided into the same number of hours, minutes, and seconds, but which are of smaller magnitude, and thus the difference of time results, in numbers, the same." **Raper to the rescue.**

In finding the longitude at sea, the *Sidereal Time at Ship* is obtained by calculation from observations of the stars themselves, but the *Sidereal Time at Greenwich*, with which to compare it, is dependent upon the accuracy of the chronometers employed in the operation, and is found as follows. To the chronometer time of observation apply its error, which, of course, gives Greenwich Mean Time. To this add the Sidereal time for the *preceding* Mean noon, taken from the last column on page II. of the month.

It now becomes necessary to change the given Greenwich Mean Time into sidereal measure by *adding* to it the *acceleration* taken from a table of time equivalents to be found on page 486 of the N. A. for 1895. This table is also given in Raper's *Epitome*, where it is numbered 23, and is used for converting intervals of mean solar time into equivalent intervals of sidereal time. In actual practice the hundredths would be rejected. *See* page 740. **How to change Clock Time into Star Time.**

EXAMPLE.

Required the Sidereal Time at *Greenwich* on March 28th, 1881, when a chronometer which was 5m. 42s. fast of G.M.T. shewed 9h. 15m. 18s. same date:— **Example of Sidereal Time at *Greenwich***

		H.	M.	S.
Time by chronometer		9	15	18·00
Chronom. fast of G.M.T.	–		5	42·00
Greenwich Mean Time		9	9	36·00
Sidereal time at *preceding* mean noon, viz., March 28th .		0	24	9·57
By Table, the acceleration for 9h. of Green. Mean Time is	+		1	28·71
" " 9m. " "	+		0	1·48
" " 36s. " "	+		0	0·10
Required Sidereal Time at Greenwich		9	35	15·86

* Page 175, nineteenth edition.

9h. 35m. 15·86s. is accordingly the *Sidereal Time at Greenwich* at the instant of 9h. 9m. 36s. Mean Time at that place, and is equal to the *Right Ascension of the Meridian* of an observer at Greenwich; or, in other words—at that moment, and at that place—the *Hour angle* of the first point of Aries is 9h. 35m. 15·86s. West.

The approximate *Sidereal Time at Ship* may, in a somewhat similar manner, be determined from the chronometer time and the longitude by account.

EXAMPLE.

Example of Sidereal Time at *ship*.

Required the Sidereal Time *at Ship* on November 18th, 1881, when a chronometer, which was 2m. 42s. slow of G.M.T., shewed 11h. 54m. 33s. same date. Longitude by account, 60° 15′ W.

		H.	M.	S.
Time by Chronometer		11	54	33·00
Chronom. slow of G.M.T.	+		2	42·00
Greenwich Mean Time		11	57	15·00
Longitude of ship in time		4	1	00·00
Mean Time at ship		7	56	15·00
Sidereal Time at *preceding* mean noon, viz., Nov. 18th . .		15	50	39·98
By Table, the acceleration for 11h. of Green. Mean Time is	+		1	48·42
,, ,, 57m. ,, ,,	+		0	9·36
,, ,, 15s. ,, ,,	+		0	0·04
The required Sidereal Time at Ship, *or* Right Ascension of the Meridian		23	48	52·80

How to find and name Star's Hour Angle.

This last is what is required in the problem, "Latitude by an Ex-meridian Altitude of a star." Then, to ascertain from it the star's hour angle, you have merely to take the difference between the *Right Ascension of the meridian*, as above, and the *Right Ascension of the star*, as given in the *Nautical Almanac.*

In working "Ex-Merids.," it is not always necessary to know whether the hour angle is East or West; but, should it be required, the following rule is not difficult to remember. In all cases, if the *Right Ascension of the meridian* exceed 24h., subtract that amount from it; then, if it be greater than the Right Ascension of the star, the hour angle is west. When the contrary is the case, it is east. Should the hour angle thus found exceed 12h., subtract it from 24h., and reverse its name.

Check to avoid mistakes.

To prevent any gross mistakes creeping into this work, it is easy to check the result by Raper's Table 27. Thus: take the difference between the Apparent Time at Ship (roughly found by clock) and the stated time of star's meridian passage, as given in the table, which will be sufficiently near the true hour angle to enable any *great* blunder in the regular work to be detected.

Gain or loss of a day in circumnavigating the Globe.

In connection with *Time*, there is one point which deserves more than a passing notice. It is the picking-up or dropping of a day, according as the globe is circumnavigated east or west-about.

One who is not familiar with the subject finds it difficult to realize that at the same moment there should be a difference of time at various parts of the earth's surface—nor is this really the case so far as *absolute* time is concerned. The *present moment* here in England is equally the *present moment* in Sydney, Australia, although the clock there marks some ten hours later than it does with us. This is accounted for by the fact that the sun, which is the divider of day and night, and all over the world the recognised marker of Time, crosses the meridian of Sydney some ten hours before it reaches ours.

Sun the domestic timekeeper of the world.

In the daily course of the sun, his advent at each meridian on the earth's surface marks the hour of noon for all places on that meridian. It is thus the sailor, more especially, reckons his time. No matter what seas he may be navigating, he considers it noon the moment the sun is "up," or on his meridian. Now, if his course lies from east to west, or if he and the sun are moving in the same direction, clearly at the instant the sun arrives at his meridian, and he strikes 8 bells, it must be past noon at the places he left yesterday, and is not yet noon at the place he hopes to reach by to-morrow.

Explanation of how time is gained or lost in navigation.

On the other hand, if he is sailing eastward, he is moving in an opposite direction to the sun—which, therefore, instead of overtaking him, as it did when he was bound towards the west, now advances to meet him, and, consequently, before it has reached the spot where he took his mid-day observation of yesterday, it will be past noon with him to-day, and getting on towards one bell. In plain language, as he goes eastward he shortens his day, and as he goes westward he lengthens it, in exact proportion to the difference of longitude made good—the constant rate in all latitudes being 1 hour for every 15° of his advance.

Let then the navigator—having started presumably from Greenwich in an easterly direction—arrive at the meridian of 180° at 1 o'clock on the morning of Tuesday the 16th (ship time); it will then be only 1 o'clock at Greenwich in the afternoon of Monday the 15th, as by meeting the sun he has got ahead of the folks at home, and anticipated their time by twelve hours. It will be mid-night with him when it is only mid-day with them. If he continues on in the same direction, and completes the other half of the voyage without altering his date, he will have gained another 12 hours on arrival at Greenwich, *no matter how long he may be in getting there*, and would probably imagine the day of his return to be, say Friday noon, when in reality it was only Thursday noon.

What to do on arriving at the meridian of 180°.

To avoid this, on passing the meridian of 180° E., he should have reckoned Monday the 15th *twice over*, which would have brought things straight at the finish. On the contrary, when reaching 180° in a westerly direction, the navigator would be exactly 12 hours *behind* Greenwich, so that if it were then 1 o'clock on Tuesday morning the 16th by *his* reckoning, it would be 1 o'clock in the afternoon of the same day at Greenwich. If he pursued his voyage westward without making the requisite alteration in his calendar, he would arrive at Greenwich, say at noon on Friday, and be surprised to learn that with the inhabitants it was noon on Saturday. To avoid this, he should have skipped a day when at 180° W. He should have called the day Wednesday, and have overlooked Tuesday altogether.

Pay attention to Greenwich date *shewn by Chronometer*.

The great point for the practical navigator to attend to is *to hold on to his Greenwich date by chronometer*, otherwise he may make the not uncommon blunder of taking out the *Nautical Almanac* elements for the wrong day, and so get adrift as to his true position.

Chronometer face—how it should be marked.

Here the marking of the chronometer face from 0 up to 23 hours would be of great service. As the dial is figured at present, there are no means of distinguishing the XII. noon from XII. midnight; whereas, if marked as suggested, 0 hour would always refer to noon, and 12 hours to midnight.

How to avoid confusion.

If, however, a man, when winding his chronometer, were to take the trouble from the very beginning of the voyage, to enter every day, on a slip of paper kept in the case, the hour A.M. or P.M., day of the week, and day of the month—*Greenwich time*—of his doing so, he could not possibly get astray. When, by-and-by, he found his own or ship date differing from that of Greenwich, he would merely have to adopt the latter, whatever it might be. Thus, having passed the meridian of 180° E., on going to wind his chronometer at 8 o'clock on Tuesday morning the 16th, he would find by his slip that at Greenwich it was 8 o'clock on Monday evening the 15th, and would accordingly instruct his chief officer to consider the day as Monday over again, and so enter it in his log.

Going east or west round the world, there will be no *real* gain or loss of a day. Otherwise a man, by continually sailing round east-about, might be considered—from the frequent repetition of a day which it entailed—to have lived longer than another who had stopped at home. In the case of the traveller, he only *appears* to gain a day, as each one of those he has lived whilst on his journey has been shorter by a certain number of minutes—which has arisen from the difference of longitude traversed between two consecutive arrivals of the sun on his meridian; whilst the day of the man who remained behind has always contained the complete 24 hours.

No *absolute* gain or loss of time in circum-navigating the world.

Again, if two men, *A* and *B*, started at the same instant on a journey round the world, the first going east and the other west, and neither made any alteration in their dates from the time of setting out till their return together on the same day, this is what would happen: *A* would believe he had arrived, say on Sunday, and *B* would persist in considering it as Friday. There would be a difference of two whole days in their reckoning; but no one would seriously entertain the idea that on this account *A* had lived 48 hours longer than *B*. The actual day of the week would, of course, be Saturday, and the *actual* time occupied by each on the journey would be precisely the same.

Curious illustration of difference of date caused by circum-navigating in opposite directions.

The reader will understand from this that *Time* may be *relative* as well as *absolute.*

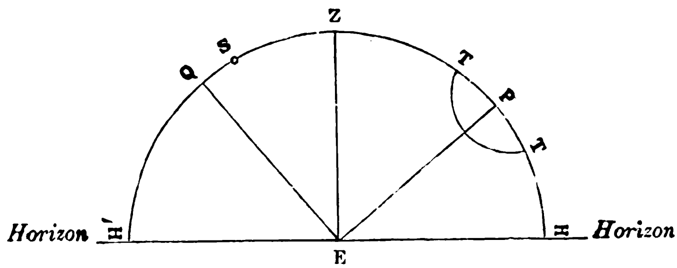
To shew this yet more clearly, let us take a very exaggerated case. Supposing it were possible for a pedestrian to walk round either pole of the earth, say at a fixed distance from it of 10 miles, the circumference of the circle which he would describe would be 60 miles, and at the rate of 2½ miles per hour he would accomplish the entire circuit in one day. If then, he started at noon, Apparent Time at place, and walked always in a westerly direction, preserving the above steady rate, he would keep pace exactly with the sun, and have it bearing either north or south, as the case might be, apparently stationary on his meridian as long as he chose to keep up his walk. His *local time* would *never* alter. If he started, say at noon on Sunday, so long as he continued to walk, *local time* would cease to progress, and it would remain noon on Sunday; but *absolute time* would go on as usual, as his weary feet and the watch in his pocket would plainly tell him.

Distinction between *relative* and *absolute* time

The following problem is so instructive in first principles that, although it scarcely belongs to the subject, and is not rigorously correct, it would be a pity to omit it.

Curious but instructive problem.

The question is—In what way could a navigator who has no knowledge of his position, and has lost all record of time, ascertain not only his correct latitude and longitude, but recover the day and date? It is presumed that he is provided with the usual nautical instruments and books.



Let the above figure be a projection of the sphere on the plane of the meridian. P is the elevated pole; Z, the zenith, EQ, the equator; and TT' any circumpolar star.

To solve the question, let the navigator observe the altitude of any circumpolar star at both its upper and lower culminations, as at T and T'; the half sum of these altitudes will give him the altitude of the pole, which is equal to the latitude of the place of observation—that is, it will give him the arc QZ. Then let the ship be hove-to, so as to keep on the same parallel of latitude until noon of next day. At noon, observe the meridian altitude of the sun; thus, the arc SH' becomes known, S being the position of the sun when on the meridian. Subtract SH' from ZH', and we have the arc SZ.

QS is the declination of the sun. Now we know QZ and SZ; hence we have $QZ - SZ = QS$, or we thus ascertain the declination at noon of the sun. This quantity is tabulated in the *Nautical Almanac* every noon; it is a constantly varying quantity—hence there can be only *one* noon to which the known declination corresponds; so by hunting this up in the *Nautical Almanac*, the day, month, and year are at once determined.

A second method of determining the date is to measure the distance between the sun and moon with a sextant (Lunar observation), or the distance between the moon and one of the principal stars. These distances are tabulated in the *Nautical Almanac.* They differ from day to day, and the difference between any two days is sufficient to fix the date. The "Lunar" would give the longitude from Greenwich. The intelligent reader will not need to be told that there are insuperable difficulties to the carrying out of the foregoing in actual practice.*

* Captain S. P. H. Atkinson has cleverly pointed out that, as the observer could not tell whether the sun was moving North or South, it would be necessary to wait and take *two* meridian altitudes to determine which side of the solstice he was on. Also, that as the observer's longitude is unknown, and as the elements in the N.A. are computed for noon *Greenwich Date*, and not for noon *at Ship*, our Nautical Rip Van Winkle would still be in a mental fog as to the exact date. To overcome this, Captain Atkinson pro-

To wind up the chapter on *Time*, it is well to know that with us the days of the week are named after the deities in the Scandinavian mythology; but in astronomy they are represented by symbols having reference to the sun and certain of the planets.

Days of the week distinguished by Symbols.

☉ Sunday (the Sun).

☾ Monday (the Moon).	♃ Thursday (Jupiter).
♂ Tuesday (Mars).	♀ Friday (Venus).
☿ Wednesday (Mercury).	♄ Saturday (Saturn).

Sometimes, when jammed for room, it is convenient to use these symbols, and they are soon learned.

Differences in duration of Northern and Southern Summer.

It may also be interesting to know that in the northern and southern hemispheres the duration of summer is not the same. The northern summer is the longer of the two, since the sun is on our side of the equator for 186½ days, and to the southward of it for the remaining 178¾ days.

This is due to the eccentricity of the earth's orbit, and the fact that we move in it faster when near the sun (our winter) than we do when further away (our summer).

In this chapter there has been no little repetition and much harping upon the same thing; but the writer will not regret the loss of space or literary effect if thereby he has succeeded in making this (generally speaking) hazy subject of *Time* any clearer to the understanding of seamen.

poses that the Lunar should be taken near the time of getting the meridian altitude, and the interval measured by watch, and allowed for in comparing with the N.A.

This, *coupled with* the meridian altitude, would fix the Greenwich Date, and the Lunar would give the G.M.T. as closely as the moon's Sem. and Hor. Parall. taken out for the approximate G.M.T. (determined by roughly corrected App. Dist.) would allow.

The Lunar then worked afresh with the elements corrected by the last found G.M.T would give a still better determination.

* A close study of the paragraphs on time—actual and relative—is not a case of "love's labour lost"; for in quite a number of instances it has been found that officers carrying on a series of observations at Noon, G.M.T., each day between New Zealand and England, *viâ* Cape Horn, have experienced a curious difficulty in determining the local data corresponding to Greenwich Mean Noon when crossing the 180th meridian.

CHAPTER VIII.

LATITUDE BY EX-MERIDIAN ALTITUDE OF A STAR.

Similarity between "Ex-merid." of Sun and Stars.

With the exception of finding the hour angle (meridian distance) *this work is exactly the same as that for the sun.* The stars, however, have manifold advantages, inasmuch as, among other things, it is generally possible to choose those which will give the best results, whereas with the sun we have to take him as we find him.

As shewn in the previous chapter, much depends in this problem on a correct knowledge of the *Time* employed in the calculation, consequently *it is important to choose such stars as will be least affected by any error in this element.*

From the slowness of their motion in altitude, it follows that the stars near either pole are the best adapted for this observation. Always give the preference, therefore, to such as have large declinations, of which the following is a list, in the order of their Right Ascensions; but the examples given further on will shew that it is by no means necessary to confine one's self to these alone.

Suitable stars—limit of visibility in opposite hemispheres.

	Declin. °		Latitude. °		Declin. °		Latitude. °
Achernar	58 S.	visible to	22 N.	Schedar	56 N.	visible to	24 S.
Canopus	53 S.	"	27 N.	Mirfack	50 N.	"	30 S.
ε Argûs	59 S.	"	21 N.	Capella	46 N.	"	34 S.
δ Argûs	54 S.	"	26 N.	Menkalinan	45 N.	"	35 S.
β Argus	69 S.	"	11 N.	Dubhe	62 N.	"	18 S.
α Crucis	62 S.	"	18 N.	Phecda	54 N.	"	26 S.
β Centauri	60 S.	"	20 N.	Benetnasch	50 N.	"	30 S.
α Centauri	60 S.	"	20 N.	Kochab	75 N.	"	5 S.
α Tri. Austr.	69 S.	"	11 N.	γ Draconis	51 N.	"	29 S.
α Pavonis	57 S.	"	23 N.	Arided	45 N.	"	35 S.
α Gruis	48 S.	"	32 N.	Alderaimin	62 N.	"	18 S.

The above latitudes of visibility are in each case calculated for a meridian altitude of 10°, but in clear weather, and under ordinary conditions of temperature and atmospheric pressure, these limits may be exceeded, as it is possible to see stars at much lower altitudes—sometimes, indeed, on rising or setting, when they are not infrequently mistaken for a steamer's mast-head light. Owing, however, to the uncertainty of refraction near the horizon, it is not usually prudent to observe bodies having a less altitude than 7° or 8°. When compelled to do so, however, it is advisable to note the barometer and thermometer, also the sea temperature, and if the conditions are abnormal, correct the mean refraction by the Auxiliary Tables 32 and 33 of Raper. In such cases, endeavour to get an observation on the opposite side of the zenith as well, which will enable you, as already explained, to detect any unusual refraction.

Precautions with low altitudes.

Another point wherein the *ex*-meridian altitude has a pull over the altitude *on* the meridian, is, that during twilight (the best time for observing) it may so happen that there is no star then culminating; whereas it would be hard lines indeed if one or two could not be found, the smallness of whose hour angle east or west permitted the use of this method. The reader cannot fail to see that, by it, the opportunities of getting the latitude are materially increased.

Increased opportunities of observation at favourable times.

Again, to watch for the transit of a star on a dark night requires no little patience, and it has a decidedly fatiguing effect on the eye. This is avoided by the ex-meridian, where one good sight—without the bother of waiting, on a possibly wet deck—is all that is required. Nor does the sextant in this latter case suffer by unnecessary exposure to the damp night air, which, by clouding the glasses, requires a frequent application of the chamois leather; and this, in its turn—unless carefully done—is apt to put the instrument out of adjustment.

All things considered, Ex-meridians are preferable to the Meridian altitude.* Compared with the gain, the extra work is trifling. The following are worked by the method of Brent, Walter, and Williams:—

***Ex*-Meridians better than observation *on* the Meridian.**

About 3 A.M. on Sunday, June 6th, 1880, the following "Ex-merids." for latitude were taken on board the s.s. "*British Crown.*" Eye 22 feet; no index error; chronom. slow of G.M.T. 3m. 57s.: barometer, 30″·52; air temperature, 58° Fahrenheit.

* *Vide* caution as to meridian alt. on pages 371-372.

Chronometer. H. M. S.			° ′
16 34 12	June 5th, observed alt.	* Altair,	50 17 S.
16 43 13	„ „	* Polaris,	48 33¾ N.
16 53 00	„ „	* Altair,	49 38¾ S.

"*British Crown*" observations.

At noon, June 6th, the same chronometer shewed 1h. 20m. 00s. (25h. 20m. reckoning from previous day), and the ship's position was 48° 44′ N., 20° 53′ W. Between 3 A.M. and noon, the ship made N. 70° E. (true), 12·2 miles an hour; therefore at the time the chronometer shewed 16h. 43m. 13s., we have for the position by account—Latitude 48° 8′ N., Longitude 23° 22′ W.

Example I.—* Altair.

	H. M. S.
Time by chronometer	16 34 12
Chronom. slow	+ 3 57
G.M.T.	16 38 09
Longitude in time	1 33 40
Mean time at ship	15 04 29
Sidereal time at *preceding* G.M. noon	4 57 09
Acceleration for 16h. 38m. 09s. ..	+ 2 44
Right Ascension of the meridian.	20 04 22
Right Ascension of * Altair.. ..	19 44 59
	M. S.
*'s hour angle	19 23 W.

	° ′
*'s observed alt.	50 17 S.
Corr. Table 38 of Raper..	− 5¼
*'s true altitude	50 11¾
Table III. C { 2″·00 Table IV.	+ 12½
Table III. C { ·04 „	+ ½
Merid. alt. at place of obs.	50 24¾
	90
Mer. zen. dist. at place of obs. ..	39 35¼ N
* Altair's declination	8 33¼ N.
Latitude at time of sight ..	48° 8½′ N

Example II.—* Altair.

	H. M. S.
Time by chronometer	16 53 00
Chronometer slow	+ 3 57
G.M.T.	16 56 57
Longitude in time	1 33 16
Mean time at ship	15 23 41
Sidereal time at *preceding* G.M. noon	4 57 03
Acceleration for 16h. 57m.	+ 2 47
Right Ascension of the meridian	20 23 37
Right Ascension of * Altair ..	19 44 59
*'s hour angle	38 38 W.

	° ′
Altair's observed altitude	49 38¾ S.
Correction, Table I. of Brent	− 5¼
*'s true altitude	49 33½
Table III. C { 2″·00, Table IV. ..	+ 49¼
Table III. C { ·04, „ ..	+ 1
Merid. alt. at place of observation .	50 23¾
	90
Merid. zen. dist. at place of observ.	39 36¼ N
* Altair's declination	8 33¼ N.
Latitude at time of sight ..	48° 09½ N

Reduction of several obs. to one time for sake of comparison.

The latitude as found by the Pole star was 48° 10′ N., and by allowing for the ship's run in the interval between sights, the first "Ex-merid.," reduced to time of observation of Pole star, gave the latitude at that moment as 48° 9½′ N., and the second "Ex-merid.," reduced in like manner, gave it as 48° 9′ N.

The following "Ex-merids." were taken on board the s.s. "*British Crown*" about 8·40 P.M. on the evening of June 6th, 1880. The position by dead reckoning at 9h. 51m. 12s. by chronometer (which shewed 1h. 20m. at preceding noon) being, latitude 49° 21′ N., longitude 18° 18′ W. Eye 22 feet for all but the North star, which was observed from the bridge, where the eye was 32 feet. Ship supposed to be making N. 70° E. (true), 12·7 miles an hour since noon. Chron. 3m. 57s. slow of G.M.T. No index error. Barom. 30″·32. Therm 57° Fahr. To economize space, only the first and last sights are shewn worked out, but the reader can work the others by way of practice, if so inclined.

Chronom. H. M. S.					Answers.
9 42 3	obs. alt.	* Arcturus .	59° 41′ S.	For sake of comparison the results are reduced to time of observation of Polaris, namely, 9h. 51m. 12s. by chronometer.	Lat. 49° 24′ N.
9 51 12	,,	* Polaris . .	48 10¾ N.		,, 49 23¾ ,,
9 53 49	,,	* Arcturus .	60 7¾ S.		,, 49 24¾ ,,
9 57 14	,,	* Spica . .	29 44¼ S.		,, 49 24½ ,,
10 5 2	,,	* Spica . .	29 29¾ S.		,, 49 24¾ ,,

Example III.—* Arcturus.

	H. M. S.
Time by chronometer	9 42 3
Chronometer slow	+ 3 57
G.M.T.	9 46 00
Longitude in time	1 13 24
Mean time at ship	8 32 36
Sidereal time at *preceding* G.M. noon	5 1 6
Acceleration for 9h. 46m.	+ 1 36
Right Ascension of the meridian ..	13 35 18
Right Ascension of * Arcturus ..	14 10 14
*'s hour angle	34 56 E.

	° ′
Observed Alt. * Arcturus	59 41 S.
Correction Table I. of Brent	− 5¼
*'s true alt.	59 35¾
Table III. C { 2″·00 Table IV. ..	+ 40¾
·40 ,, ..	+ 8
·03 ,, ..	+ 0¼
Merid. alt. at place of observation .	60 25
	90
Merid. zen. dist. at place of observ.	29 35 N
*'s declination	19 48¼ N.
Latitude at time of sight ..	49 23¼ N.
Corr. for ship's run	+ ¾
Lat. at 9h. 51m. 12s. by chronometer	49° 24¼′ N.

Example IV.—* Spica.

	H. M. S.
Time by chronometer	10 5 2
Chronometer slow	+ 3 57
G.M.T.	10 8 59
Longitude in time	1 13 2
Mean time at ship	8 55 57
Sidereal time at *preceding* G.M. noon	5 1 6
Acceleration for 10h. 9m.	+ 1 40
Right Ascension of the meridian	13 58 43
Right Ascension of * Spica	13 18 55
*'s hour angle	39 48 W.

	° ′
* Spica's observed altitude	29 29¾ S.
Correction—Table I. of Brent ..	− 6¼
*'s true alt.	29 23½
Table III. C. { 1″·00 Table IV. ..	+ 26¾
·40	+ 10¾
·05	+ 1½
Merid. alt. at place of observation	30 01¾
	90
Mer. zen. dist. at place of obs. ..	59 58¼ N.
* Spica's declin.	10 32¾ S.
Latitude at time of sight	49 25½ N.
Corr. for ship's run	− 1
Lat. at 9h. 51m. 12s. by chronometer	49° 24′ N.

In Example III. the number of minutes in the hour angle exceeds the number of degrees in the meridian zenith distance—which, in a star like Arcturus, having small declination, is an unfavourable condition; nevertheless, the observation is worked out to shew that, if carefully made, and the time used is reliable, the result will still be good. Unfavourable condition.

Chronometer.

H. M. S.			° ′
16 34 12	June 5th, observed alt.	* Altair,	50 17 S.
16 43 13	„ „	* Polaris,	48 33¾ N.
16 53 00	„ „	* Altair,	49 38¾ S.

"*British Crown*" observations.

At noon, June 6th, the same chronometer shewed 1h. 20m. 00s. (25h. 20m. reckoning from previous day), and the ship's position was 48° 44′ N., 20° 53′ W. Between 3 A.M. and noon, the ship made N. 70° E. (true), 12·2 miles an hour; therefore at the time the chronometer shewed 16h. 43m. 13s., we have for the position by account—Latitude 48° 8′ N., Longitude 23° 22′ W.

Example I.—* Altair.

	H. M. S.		° ′
Time by chronometer	16 34 12	*'s observed alt.	50 17 S.
Chronom. slow	+ 3 57	Corr. Table 38 of Raper	− 5¼
G.M.T.	16 38 09	*'s true altitude	50 11¾
Longitude in time	1 33 40	Table III. C { 2″·00 Table IV.	+ 12½
		·04 „	+ ½
Mean time at ship	15 04 29		
Sidereal time at *preceding* G.M. noon .. .. .. } ..	4 57 09	Merid. alt. at place of obs.	50 24¾
			90
Acceleration for 16h. 38m. 09s. ..	+ 2 44		
Right Ascension of the meridian.	20 04 22	Mer. zen. dist. at place of obs. ..	39 35¼ N
Right Ascension of * Altair	19 44 59	* Altair's declination	8 33½ N.
	M. S.	Latitude at time of sight ..	48° 8¾′ N
*'s hour angle	19 23 W.		

Example II.—* Altair.

	H. M. S.		° ′
Time by chronometer	16 53 00	Altair's observed altitude	49 38¾ S.
Chronometer slow	+ 3 57	Correction, Table I. of Brent	− 5½
G.M.T.	16 56 57	*'s true altitude	49 33¼
Longitude in time	1 33 16	Table III. C { 2″·00, Table IV. ..	+ 49¼
		·04, „ ..	+ 1
Mean time at ship	15 23 41		
Sidereal time at *preceding* G.M. noon .. .. .. } ..	4 57 09	Merid. alt. at place of observation .	50 23½
			90
Acceleration for 16h. 57m.	+ 2 47		
Right Ascension of the meridian	20 23 37	Merid. zen. dist. at place of observ.	39 36½ N.
Right Ascension of * Altair ..	19 44 59	* Altair's declination	8 33¼ N.
		Latitude at time of sight ..	48° 09¾′ N
*'s hour angle	38 38 W.		

Reduction of several obs. to one time for sake of comparison.

The latitude as found by the Pole star was 48° 10′ N., and by allowing for the ship's run in the interval between sights, the first "Ex-merid.," reduced to time of observation of Pole star, gave the latitude at that moment as 48° 9½′ N., and the second "Ex-merid.," reduced in like manner, gave it as 48° 9′ N.

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Chronom. H. M. S.					Answers.
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9 51 12	"	* Polaris . .	48 10¾ N.		" 49 23¾ "
9 53 49	"	* Arcturus .	60 7¾ S.		" 49 24¾ "
9 57 14	"	* Spica . .	29 44½ S.		" 49 24½ "
10 5 2	"	* Spica . .	29 29¾ S.		" 49 24¾ "

Example III.—* Arcturus.

	H. M. S.
Time by chronometer	9 42 3
Chronometer slow	+ 3 57
G.M.T.	9 46 00
Longitude in time	1 13 24
Mean time at ship	8 32 36
Sidereal time at *preceding* G.M. noon	5 1 6
Acceleration for 9h. 46m.	+ 1 36
Right Ascension of the meridian ..	13 35 18
Right Ascension of * Arcturus ..	14 10 14
*'s hour angle	34 56 E.

	° ′
Observed Alt. * Arcturus	59 41 S.
Correction Table I. of Brent	− 5¼
*'s true alt.	59 35¾
Table III. C { 2″·00 Table IV. ..	+ 40¾
·40 " ..	+ 8
·03 " ..	+ 0¼
Merid. alt. at place of observation .	60 25
	90
Merid. zen. dist. at place of observ.	29 35 N
*'s declination	19 48¼ N.
Latitude at time of sight ..	49 23¼ N.
Corr. for ship's run	+ ¾
Lat. at 9h. 51m. 12s. by chronometer	49° 24¼′N.

Example IV.—* Spica.

	H. M. S.
Time by chronometer	10 5 2
Chronometer slow	+ 3 57
G.M.T.	10 8 59
Longitude in time	1 13 2
Mean time at ship	8 55 57
Sidereal time at *preceding* G.M. noon	5 1 6
Acceleration for 10h. 9m.	+ 1 40
Right Ascension of the meridian	13 58 43
Right Ascension of * Spica	13 18 55
*'s hour angle	39 48 W.

	° ′
* Spica's observed altitude	29 29¾ S.
Correction—Table I. of Brent ..	− 6¼
*'s true alt.	29 23½
Table III. C. { 1″·00 Table IV. ..	+ 26¾
·40	+ 10¾
·05	+ 1¼
Merid. alt. at place of observation	30 01¾
	90
Mer. zen. dist. at place of obs. ..	59 58¼ N.
* Spica's declin.	10 32¾ S.
Latitude at time of sight	49 25½ N.
Corr. for ship's run	− 1
Lat. at 9h. 51m. 12s. by chronometer	49° 24′N.

Unfavourable condition.

In Example III. the number of minutes in the hour angle exceeds the number of degrees in the meridian zenith distance—which, in a star like Arcturus, having small declination, is an unfavourable condition; nevertheless, the observation is worked out to shew that, if carefully made, and the time used is reliable, the result will still be good.

The foregoing examples are *bona fide*, having been actually taken on board the "*British Crown*" on a North Atlantic passage. They were selected at hap-hazard from among a large number of others equally good, and prove very conclusively the splendid results which may be obtained by the use of the ex-meridian problem.

When the time is in error, the reductions on one side of the meridian will be too great, and on the other too small; if, therefore, two stars on opposite sides of the meridian—having nearly equal hour angles—be observed within a few minutes of each other, the mean of the two results (each being first reduced to the same instant of time) will be free from any error due to this cause. Or, what amounts to the same thing, it may be possible to get the *same* star at nearly equal distances on *both* sides of the meridian, but in this last case the ship should be stationary, or nearly so, or allowance made for change of position (see page 483)

"Ex-merids." of planets.

Ex-meridians of the planets Venus, Mars, Jupiter, and Saturn, are worked in a similar manner to the fixed stars. As, however, their Right Ascensions and Declinations are constantly varying (the Latin word *Planeta* means a *wandering star*), it is necessary to correct them for the Greenwich Date.* They will be found in the *Nautical Almanac* for 1895, between pages 234 and 265. In other respects the problem is precisely the same, even to the correction of the observed altitude,† so that an example is unnecessary.

"Ex-merids." *below* the Pole.

So far, ex-meridians *above* the Pole have only been treated of; but as occasion may offer to observe them *below* the Pole, and the results derived from this problem being just as correct as any other, it is proper to give a few examples.

On board the s.s. "*British Crown*," about 11 P.M. on Saturday, June 19th, 1880, the clouds were seen to break low down on the northern horizon, and disclose a bright star shining in the midst of a small clear space. To the eye there was nothing by which this solitary star could be recognized. A bearing of it by standard compass, when corrected for variation and deviation, gave its *true* azimuth as N. 3° W., making it evident that the star—whichever it might be—was approaching its lower culmination.

* "The GREENWICH DATE is the time at Greenwich corresponding to any given time elsewhere." See Raper, para. 481, page 175, nineteenth edition.

† Parallax may be disregarded. In the case of Jupiter and Saturn it is an utterly insignificant quantity; and in that of Venus, seldom exceeds 15". Since it is, in all cases, the estimated *centre* of the radiant point which will be brought down to the horizon, semi-diameter may also be disregarded.

Reference to Table 27 of Raper shewed that Capella had passed the meridian *above* the Pole at 11h. 9m. in the forenoon, and would consequently pass the meridian *below* the Pole at 11h. 7m. on that very night. This, therefore, must be the star which, out of the many in the heavens, happened to be the only one visible. On computing Capella's meridian altitude,* its close agreement with that observed made the identity of the star no longer a matter of conjecture. It was accordingly decided to secure sights, to be worked up *as ex-meridians below the Pole,* and also, if possible, to get its *Lower meridian altitude.*

How to compute meridian altitude *below* the Pole.

As a check on Capella—the altitude being so very small—it was important to get a star to the southward, and on referring again, with this in view, to the same Table in Raper, it was discovered that the star Ras Alhague (α Ophiuchi) would pass the meridian to the southward at 11·34 P.M. But as the sky was completely clouded over, with the exception of the aforesaid small break to the northward, and as, moreover, the writer was unacquainted with this particular star, it was not likely the wish would be gratified; *nevertheless the meridian altitude of Ras Alhague was computed, in readiness to place upon the sextant in the event of the clouds breaking up.* This actually occurred shortly after, and through a rift in the clouds the needful sight of the coveted star was obtained.

How to be ready for flying shots

Had the approximate altitude not been calculated beforehand, and the sextant set to it, the observation would certainly have been lost; as the star, with three or four others, only remained visible for half a minute or so, and could not, even if recognized, have been brought down to the horizon with exactness in so short a time.

The following are the observations as actually taken, but want of space does not permit of them all being worked out:—

Chronometer.	H.	M.	S.			°	′	
(a)	12	33	32	observed alt.	☉ Capella	5	32¼	N.
(b)	12	43	45	"	"	5	27¼	"
(c)	12	50	24	"	"	5	25¼	"
(d)	12	53	00	"	"	5	25¼	"
(e)	12	57	9	"	"	5	25¾	"
(f)	13	10	1	"	"	5	28	"
(g)	13	20	48	"	"	5	34¾	"
(h)	13	26	19	"	☉ α Ophiuchi	53	22¼	S.

Eye 30 feet. Index error + 45″. Chronometer slow of G.M.T. 4m. 00s.

Barometer, 29″·40. Air, 56°. Water, 57°. Position by account at 12h. 53m. 00s. by chronometer: Latitude, 49° 15′ N.; Longitude, 25° 53′ W. Ship making S. 70° W. (true) 11·2 knots.

For sake of comparison, the various latitudes in the answers are all reduced, for the run of the ship, to 12h. 53m. by chronometer, at which time Capella was *on the meridian below the Pole.*

---

* Rule for computing the approximate meridian altitude *below* the Pole:—From the latitude by account subtract the star's polar distance. Simple enough! Isn't it?

Example I. (*a*).

	H.	M.	S.
Time by chronometer	12	33	32
Chronometer slow	+	4	00
G.M.T.	12	37	32
Longitude in time..	1	43	00
Mean time at ship	10	54	32
Sidereal time at *preceding* G.M. noon	6	52	21
Acceleration for 12h. 37m. 32s. ..	+	2	5
Right Ascension of the meridian ..	16	48	58
Right Ascension of * Capella	5	7	51
Capella west of the meridian, *above* the pole..	11	41	07
	12		
Capella's hour angle west of the meridian, *below* the pole		M. 18	S. 53

	°	′	″
Capella's observed altitude.. ..	5	32	15
Index error	+	0	45
	5	33	0
Dip	−	5	24
	5	27	36
Refraction	−	9	15
Capella's true altitude	5°	18′	21″
Capella's declination	45	52	30
* C. 0·	+	0	0
·9	+	5	25
·00	+	0	0
	45	57	55
	90		
	44	2	5
True altitude	5	18	21
Latitude at instant of obs.	49°	20′	26″ N
Ship's run	−	1	15

Latitude 49° 19¼′ N.
At 12h. 53m. by chronometer.

Rule A of Brent, quoted above, specifies that in the case of ex-meridians *below* the pole, the value of *C* is to be taken from that part of Table III. where the declination is of a *contrary* name to the latitude.

Rule B specifies that, in the case of ex-meridians *below* the pole, the correction from Table IV. is to be *subtracted* from the altitude, or, which is the same thing in the end, added to the declination.

Example II. (*b*).

	H.	M.	S.
Time by chronometer	12	43	45
Chronometer slow	+	4	00
G.M.T.	12	47	45
Longitude in time	1	43	11
Mean time at ship	11	04	34
Sidereal time at *preceding* G.M. noon	6	52	21
Acceleration	+	2	6
Right Ascension of the meridian ..	16	59	1
Right Ascension of * Capella	5	07	51
Hour angle west of meridian, *above* the pole	11	51	10
	12		
Hour angle west of meridian, *below* the pole		M. 8	S. 50

	°	′	
Capella's obs. alt. *below* the pole	5	27¾	
Index error	+	¼	
	5	28	
Corr. Table 38 of Raper..	−	14¼	
* Capella's true altitude	5°	13¾′	
Capella's declination	45	52½	N.
* C. 0″·90	+	1¼	
	45	53¾	
	90		
	44	06¼	
Capella's true alt.	5	13¾	
Latitude at time of observ... ..	49°	20′	N.
Corr. for ship's run	−	¾	
Lat. at 12h. 53m. by chron.	49°	19¼′	N.

* Entering Table III., with latitude by account 49° N., and declination 46° N. (contrary names, *see Rule A*), gives *C* 0″·90.
From Table IV.. with Hour Angle 19m. 0s., and *C* 0″·90, we obtain the above correction.

Example III. (*d*).

In strictness, this example, not being an ex-meridian, belongs to a previous chapter, but it is introduced so that the resulting latitude may be compared with that given by the other sights.

	°	′	
Observed alt. of ✱ Capella on the merid. *below* the pole .	5	25¼	N.
Index error	+	¾	
	5	26	
Corr. Table 38 of Raper	−	14¼	
✱ Capella's true meridian alt.	5	11¾	N.
✱ Capella's polar distance	44	7½	N.
Lat. at 12h. 53m. by chronom.	49°	19¼′	N.

Example IV. (*g*).

	H.	M.	S.
Time by chronometer	13	20	48
Chronometer slow	+	4	00
G.M.T.	13	24	48
Longitude in time	1	43	57
Mean time at Ship	11	40	51
Sidereal time at *preceding* G.M. noon	5	52	21
Acceleration	+	2	13
Right Ascension of the meridian ..	17	35	25
Right Ascension of ✱ Capella ..	5	7	51
Hour angle *west* of meridian, *above* the pole	12	27	34
	12		
		M.	S.
Hour angle *east* of meridian, *below* the pole		27	34

Note.—Attention is called to the change in name of the hour angle. As the *westerly* hour angle *above* the pole is greater than 12 hours, the excess is of necessity equal to the hour angle *east* below the pole. Refer to diagram on page 380.

	°	′	
✱ Capella's obs. alt. *below* the pole	5	34¾	N.
Index error	+	¾	
	5	35½	
Correction Table 38 of Raper ..	−	14	
✱ Capella's true alt.	5°	21½′	
	°	′	
Capella's declination	45	52½	N
*C. 0″·90	+	11½	
	46	04	
	90		
	43	56	
Capella's true alt.	5	21½	
Lat. at time of observation ..	49	17½	
Correction for ship's run	+	1¾	
Latitude at 12h. 53m. by chronom.	49°	19¼′	N

* Entering Table III. of Brent, with Lat. by account 49° N., and declination 46° N. (contrary names, *see Rule A*), gives *C* 0″·90.

From Table IV., with hour angle 27m. 34s., and *C* 0″·90 we obtain correction as above

EXAMPLE V. (*h*).

A check observation.

* Ras Alhague *above* the pole to the southward. Taken as a check on Capella.

	H. M. S.
Time by chronometer	13 26 19
Chronometer slow	+ 4 00
G.M.T.	13 30 19
Longitude in time	1 44 6
Mean time at ship	11 46 13
Sidereal time at *preceding* G.M. noon	5 52 21
Acceleration for 13h. 30m. 19s. ..	+ 2 13
Right Ascension of the meridian ..	17 40 47
Right Ascension of * Ras Alhague	17 29 25
Hour angle of Ras Alhague (α Ophiuchi)	11m. 22s. W.

	° ′
Obs. alt. of * Ras Alhague	53 22½ S.
Index error	+ ⅓
	53 23¼
Correction—Table 38 of Raper, or Table L of Brent	− 6
*'s true altitude	53 17¼
* C {2″·00..	+ 4½
C {·10..	+ 0¼
Merid. alt. at place of obs. .. .	53 21¾
	90
Merid. zen. dist. at place of obs. ..	36 38¼ N.
*'s declination	12 39 N.
Latitude at time of sight	49 17¼ N.
Correction for run	+ 2
Latitude at 12h. 58m. by chron. ..	49° 19¼′ N.

About 9.15 P.M., Monday, June 21st, 1880, being in latitude by acc. 45° 20′ N., longitude 37° 57′ W., from the bridge of the s.s. *British Crown*, Capella and the North Star were observed for latitude. On referring to Raper's Table 27, the former was found to be west of the meridian below the Pole, and the North Star east of it. Eye, 32 feet. Arc error, +10″. Index error, +20″. Chronometer slow of Greenwich mean time, 4m. 0s. Barometer, 29″·98. Air, 46°. Water, 59°.

Chronometer 11h. 38m. 34s., observed alt. * Capella - - - 4° 51¼′ N.
" 11h. 41m. 20s., " " North Star - 44° 13¼′ N.

EXAMPLE VI.

	H. M. S.
Time by chronometer	11 38 34
Chronometer slow	+ 4 00
G.M.T.	11 42 34
Longitude in time	2 31 48
Mean time at ship	9 10 46
Sidereal time at *preceding* G.M. noon	6 00 14
Acceleration for 11h. 43m.	+ 1 56
Right Ascension of the meridian ..	15 12 56
Right Ascension of * Capella ..	5 7 51
*'s hour angle west of meridian, *above* the pole	10 5 5
	12
*'s hour angle west of meridian, *below* the pole..	1 54 55

	° ′
Obs. alt. Capella *below* the pole ..	4 51¼ N.
Arc and index errors	+ ½
	4 52
Correction—Table 38 of Raper ..	− 15¾
* Capella's true altitude	4 36¼

In this case, the big hour-angle puts it "out of bounds" for Ex-meridian Tables, so we must fall back on calculation. The formula in Jeans' Navigation (page 138 of 3rd Edition) is given on next page, *but it must not be employed when the declination is less than 10°*. With smaller declinations the deduced latitude may be very much in error.

* Entering Table III., with latitude by account 49¼° N. and declination 12¾° N. (same name), gives C 2″·10.

From Table IV., with hour angle 11m. 22s. and C 2″·10 we obtain correction + 44¼′ as above.

JEANS' METHOD.

Declin. 45° 52½′ N. Cotang.	9·98673	........Cosec	10·14398
Hour angle 1h. 54m. 55s. Cosine	9·94295	........Arc Z, Sine	9·88180
		Alt. 4° 36½′, Sine	8·90495
Arc Z ......Cotang	9·92968	Arc Y, Cosine..	8·93078

	°	°	′		°	′	
Z	90	− 49	37	=	40	23	N.
Y	90	− 85	6½	=	4	53½	N.
			Latitude		45	16½	N.

EXAMPLE VII. (Pole Star *N. A.* Method).

	H. M. S.
Time by chronometer	11 41 20
Chronometer slow	+ 4 00
G.M.T.	11 45 20
Longitude in time	2 31 48
Mean time at ship	9 13 32
Sidereal time at *preceding* G.M. noon	6 00 14
Acceleration for 11h. 45m.	+ 1 56
Right Ascension of the meridian ..	15 15 42

	° ′
Observed alt. at Pole Star	44 13¾
Index and arc errors	+ ¼
	44 14
Correction—Table 38 of *Raper* . ..	− 6½
	44 07½
Constant	− 1
Reduced Altitude	44 6½
First correction	+1 9¼
Second correction	+ 0¼
Third correction..	+ 0¾
Latitude	45° 17′ N.

The very close agreement of all these results might lead those not well posted in star work to suspect that they had been "cooked." Such, however, is not the case. Wherever the name of the ship is given, the observations are those which were actually taken, *and have not been altered in any way whatsoever.* In many instances (of which this is one) the stars were observed and calculated in the presence of the officers of the vessel, who can answer for the perfect honesty of the work. This is mentioned to dispel any doubts as to what stars are really capable of. The *beginner* can scarcely hope for such a nice accordance of results, but a moderate amount of perseverance will prove the truth of the adage—"Practice makes perfect."

In Example VI. Capella has been treated as an ex-meridian for latitude, but from its very large hour angle (1h. 54m. 55s.) putting it beyond the prescribed limits, it must be regarded as an extreme case, and is expressly chosen on that account to assist in illustrating what will presently be said about the North star. An error of 15′ in the *longitude* (equal to 1 minute in the Time) would put the result wrong some three and a half miles, shewing the impropriety of placing dependence on ill-conditioned observations. If Capella's declination were but larger (say 70° instead of only 46°), a similar error in the time would not affect the result nearly so much, proving that greater liberties in this

Why stars near the Poles should be chosen for "Ex merids."

respect can be taken with the stars near either Pole, such, for example, as Dubhe, and the brilliant one in the foot of the Southern Cross.

Important exception.

To these, therefore, the rule for the sun, that the number of *minutes* in the hour angle should not exceed the number of *degrees* in the meridian zenith distance, does *not* apply.

The most notable instance of this is to be found in the North star, which is so close to the Pole that (as previously stated) an error in the time of half an hour, when near its upper or lower meridian passage, will fail to produce an error of even one mile in the result.

Pole Star problem merely an "Ex-merid." *in disguise.*

It has probably never occurred to the nautical reader, when figuring out the "Latitude by Pole star," that to all intents and purposes he is working an ex-meridian. Such, however, is really the case, though ninety-nine out of every hundred are deluded into believing it to be a *special* problem, peculiar to this star alone.

Construction of table for use with Pole star.

The plain fact is, that the North star's extreme slowness of motion, due to its small diurnal circle, permits of a handy table being calculated to do away with the tedium of the longer process. A somewhat similar table might, indeed, be computed for any other circumpolar star, but in no sense would it pay to do so. If the reader be curious to know how this table is formed, he will find a very easily understood account of it in the explanation to Raper's Table 51.

To shew that the familiar North star problem is nothing more than an ex-meridian *in disguise*, Example VII. is here given over again, worked out similarly to Capella.

	H.	M.	S.
Right Ascension of meridian, as before	15	15	42
Right Ascension of Pole star, N.A., page 314	1	14	43
Hour angle west of meridian *above* the pole	14	00	59
	12		
Hour angle east of meridian *below* the pole	2	00	59

Jeans' Formula (2nd Method) for Working Ex-Meridians.

Declin. 88° 40′ N. Cotang 8·36690	......Cosecant...............10·00012
Hour angle 2h. 0m. 59s. Cosine 9·93645	Arc Z Sine........... 9·99991
	Alt. 44° 7¾′ Sine ... 9·84278
Arc Z 88° 51′ Cotang 8·30335	Arc Y, Cosine ...... 9·84281

Z 90° − 88° 51′ = 1° 9′ N.
Y 90 − 45 52 = 44 8 N.

Latitude ....45° 17′ N.

Note.—In this case, the error in the latitude due to an error of one minute in the hour angle is only 10″.

The writer is not aware of ex-meridians *below the Pole* having been treated of in any other work on navigation prior to the publication of "Wrinkles." It is hoped their practical utility has been fully demonstrated.

Once more attention is called to the importance of being able —whether by day or by night—to put one's finger on the correct Apparent Time at ship. Just here it will be sufficient to say briefly that observations for time, made on or near the Prime Vertical, are to all intents and purposes independent of the latitude: an error of 20′ or even 30′ in this element will not affect the time to any appreciable extent. **Time observations—a necessary routine.**

Having thus obtained the correct time, it may be relied upon to determine the correct latitude by an ex-meridian, even when the body employed is unfavourably situated in declination and its hour-angle outside the ordinary limit. The ordinary limit is that the number of *minutes* in the hour-angle shall not exceed the number of *degrees* in the meridian zen. dist. But we cannot always command the maintenance of this limit any more than we can many other theoretical points in practical work, nor need we throw up our hands on this account so long as we know how to circumvent the difficulty. To repeat:—Circumpolar stars permit of greater liberties with their hour-angles than do those of small declination. With the first named, an approximation is sufficient; with the latter, should the usual limits be exceeded, the hour-angle *must* be accurate, and Chapter X. will make it clear how this can be ensured so long as wind and weather are not outrageously bad.

Whenever circumstances permit, "stand-by" sights should be taken by the officer of the watch and entered in a book kept for this express purpose. If not required, they need not be worked out There can be no objection to them: they won't bite, nor will they cost anything for board and lodging. **Reserve sights.**

A suitable form can be ruled with columns giving date, hour by clock, chronometer time, altitude, name of body observed, value of observation, patent log reading, height of eye, and initials of observer.

To finish with this problem—Do not forget that the latitude found by an ex-meridian (whether above or below the Pole) is that of the ship *at the moment of observation,* and if required for any other time, must be reduced to it, according to the course and distance made in the interval. BEAR THIS IN MIND.

CHAPTER IX.

LECKY'S **A B C** TABLES.

Original mission of Burdwood and Davis.

Undoubtedly, within the comparatively narrow limits assigned to the Azimuth Tables of Burdwood and Davis, there is nothing can touch them for minute accuracy and despatch; but in the present more advanced state of navigation, these limits are too restricted in more directions than one, and to enlarge them to the extent now demanded would entail in each case a ponderous tome.

There can be no reasonable doubt that their principal function was to give the *Sun's* true azimuth—*in connection with compass work*—up to the point when his altitude would no longer permit of accurate observation with the appliances then in use: for example, where the altitude would exceed 60° the columns are left blank. From this it is evident, also, that it was either forgotten or ignored—probably the latter—that the Azimuth might be a useful factor in certain problems quite apart from the more commonplace determination of compass errors.

Again, neither book goes beyond 23° of Declination, and the inference is that Lunar and Stellar observations were hardly included in the original programme, or at all events were but a secondary consideration; indeed, when Burdwood's Tables were produced, now upwards of a quarter of a century ago, star work of any kind—more especially Azimuth—was as "Caviare to the multitude."

No such exception can be taken to the A B C tables, which are framed to meet *all* cases. In this go-ahead age one thing quickly supplants another—the improver won't be denied; and so it happens that in the very complete form here presented to the seaman, the author's A B C tables have shorn Burdwood and Davis of much of their glory. In the first place, they are altogether unsurpassed for determining a ship's position, in conjunction with A. C. Johnson's far-famed rendering of the 'Double Chronometer' problem, whether applied to sun, moon, or stars·

and incidentally they give the error in the Longitude for each 1′ of error in the Latitude worked with.

Writer's improvements

As *Azimuth Tables* they are susceptible of any desired degree of accuracy. Though contained in but few pages, they are available for all parts of the globe between 60° N. and 60° S., *and for all hour angles.* In the first two pages of A and B respectively, where interpolation would otherwise be somewhat difficult, the hour angles are given for *each* minute; the next three pages of each give them for every *second* minute; and the remainder, as in Burdwood and Davis, give them for every *fourth* minute. The advantage is manifest.*

Comprehensiveness of present Tables.

The plan adopted in Table A has been modified in its counterpart B. After much consideration the latter was divided into two parts, so as better to meet the wants of the Navigator. The upper half is on the same lines as Table A; the Declination having been extended to 29°, it includes the Sun and Moon; the planets Venus, Mars, Jupiter, and Saturn; such well-known stars of the 1st mag. as Sirius, Spica, Procyon, Arcturus, Altair, Antares, Pollux, Betelguese, Regulus, Rigel, and Aldebaran; also about sixteen other zodiacal stars of the 2nd mag., all useful either for azimuth or position finding. These, when supplemented by the twenty stars specified by name in the lower half of the Table, offer a wide choice to the observer, in whatever part of the world he may be, or at whatever hour he may desire to invoke their assistance.

This arrangement, it is believed, will be found more convenient than the easier plan of carrying out the Declination to 60°, seeing that in the purely stellar portion there will be no occasion to interpolate for parts of a degree, a matter which is unavoidable in the upper portion, though the extent to which it may be carried will, of course, depend upon circumstances taken in connection with the Navigator's requirements. Usually, interpolation *at sight* will be sufficient, and where greater refinement is desired, very little experience will teach how to *guess* the number pretty correctly without resorting to the delay of figuring it out. Experience will also teach whether the numbers should be taken out to three places of decimals, or only to two. It will be found that in the smaller hour angles three decimals are not needed.

Duplicate stars.

In taking the quantities from the lower portion of B, *a* Crucis may be substituted for Dubhe; Mirfack for Benetnasch; and Arided for Menkalinan, as the declinations of the respective pairs correspond sufficiently to permit of this. The lower portion of B is therefore really available for three more stars than shewn.

* Now published separately, in greatly extended form, under the title of "Lecky's General Utility A B C and D Tables."

Table C speaks for itself. Like A and B, it gives the error in the Longitude due to an error of 1′ in the Latitude, but in a more direct manner. This being so, it may be asked, What is the use of having two ways of accomplishing the same object? This is easily answered, and what is more, the answer will be appreciated. *The one method is sometimes more convenient than the other, and in this particular case "it is well to have two strings to your bow."* This will be more apparent after a perusal of the chapter on Simultaneous Altitudes.

To enter Table A, the Latitude and *Hour Angle* are necessary; for Table B, the Declination and Hour-angle; and for Table C, the Latitude and *Azimuth* are necessary. Now, Burdwood and other cut-and-dry Tables are unfortunately not always at hand, and to find the azimuth may be difficult, in which case use Tables A and B, and the 'Error' having been found by their assistance, the *Azimuth* can at once be taken from C. So that, whatever hobble the Navigator may be in, the Tables amicably pull together to extricate him. The remarks already made respecting interpolation and places of decimals also apply to C.

Mr. Johnson, *for his purpose,* evidently considers two decimals to be sufficient, and no doubt, owing to its greater conciseness, there will be found many to give the preference to his Table* as compared with C, which latter has mostly three places of decimals. The extra labour and cost have been incurred to keep it uniform with A and B, also to permit of the Azimuth being determined with greater precision; for this purpose, two places of decimals are hardly sufficient in the larger azimuths, though more than ample in the smaller ones.

Places of decimals.

When experts in their use desire to drop the third decimal, let them observe the following rule:—With A and B as given, take their sum or difference as will presently be explained; *then,* in cutting off the third decimal, should it be 6 or upwards, add 1 to the second decimal. If, however, the third decimal be 5 or under, do not alter the second decimal. The same applies to C.

For example 3′·144 is 3′·14.
„ 3′·145 is 3′·14.
„ 3′·146 is 3′·15.

The explanation why the first and last pages of Table C are printed in red will be met with further on.

* Table I. in previous editions of "Wrinkles;" to be still found in Johnson's pamphlet, *On finding the Latitude and Longitude in Cloudy Weather.*

TO FIND FROM A AND B THE ERROR IN THE LONGITUDE DUE TO AN ERROR OF 1′ IN THE LATITUDE.

Enter Table A with the Hour-Angle and Latitude.

Always prefix the + sign, *except when the Hour-Angle exceeds 6 hours.*

Enter Table B with the Hour-Angle and Declination; or in the case of lower portion, with the Hour-Angle and star.

When Latitude and Declination are of contrary names, prefix the + sign; but when of same name prefix the − sign.

Whether the arithmetical sum or difference of A and B is to be taken as the 'Error' depends upon the following rule:—

With like signs: add, and prefix the common sign.

With unlike signs: take the difference, and prefix the sign of the greater. *This is Algebraic Addition.*

Example 1. What is the error produced in the Longitude for each 1′ of error in the Latitude when the Hour-Angle of the body observed is 1h. 58m. P.M., its Declination 29° N., and the Latitude of the observer is 24° S.?

A	+	·787
B	+	1′·126
'Error'	+	1′·913

Example 2. Use same data as before, but in this case let the Latitude be North.

A	+	·787
B	−	1′·126
'Error'	−	0′·339

Example 3. Hour-Angle 6h. 20m. P.M. Declin. 27° N. Lat. 20° N.

A	−	·032
B	−	·511
'Error'	−	0′·543

Example 4. Hour-Angle of ✱ *a Crucis* 7h. 28m. East. Lat. 50° S.

A	−	·481
B	−	2·076
'Error'	−	2·557

TO FIND THE AZIMUTH BY THE A B C TABLES.

There are a variety of modes, according to fancy and the precision aimed at. Of the two here given, the first is the shorter, being an affair of simple inspection, but in point of time there is really very little between them.

METHOD 1.

Enter C with Latitude at the side, and 'Error' in the body of the Table. The Azimuth will be found at the head of the column. By interpolation at sight it can be taken out to half a degree or less.

METHOD 2.

To the log. of the 'Error' add the cosine of the Latitude, never using more than four places of decimals. Their sum will be the Cotangent of the Azimuth.

Delusive appearances

NOTE.—The Azimuth by this method, being obtained to degrees *and minutes* of arc, has a fascinating *appearance* of exactness which is very illusory: for it must not be lost sight of that the accuracy of the result depends entirely upon the accuracy of the data used in finding the 'Error,' which latter forms one of the arguments in the final process. *Do not forget the parable of the man who built his house on a sandy foundation.*

In this respect the A B C tables are no better and no worse than Burdwood's or any other Azimuth Tables. To repeat; they will give results accurate in proportion to the accuracy of the data employed. What Tables can do more?

When adopting Blackburne's A and B tables (see Preface) these and other considerations led to the rejection of his Tables I. and II. for finding the Azimuth. Captain Blackburne may possibly think his own mode the best, but we all know that "Doctors differ," and that every father believes his own grey goose to be a white swan.

RULE FOR NAMING THE AZIMUTH.

In North Latitude. Put N for a − 'Error'; and S for a + 'Error.'
In South Latitude. Put S for a − 'Error'; and N for a + 'Error.'

EXAMPLES. (Same as before).

Example 1. *Method 1.* (By inspection).

Entering Table C with Lat. 24° S., and 'Error' + 1·913, at a glance we find the Azimuth to be 29¾°. Being South Lat. and a

+ 'Error," we name the Azimuth *North;* the Hour-Angle being P.M., the object is of course *west* of the meridian. Therefore the complete answer is

N. 29¾° W.

Example 1, *Method 2* (by calculation).

'Error' + 1'·913	Log. . .	0·2817
Latitude 24° S.	Cosine . .	9·9607
Azimuth, N. 29° 47' W.	Cotangent	10·2424

Example 2, *Method 1.*

Entering Table C with Lat. 24° N., and 'Error' – ·339, we find the Azimuth to be about 72¾°. Being North Latitude and a – 'Error' we name the Azimuth *North;* the Hour-Angle being P.M., the object is *west* of the meridian. Therefore the complete answer is

N. 72¾° W.

Example 2, *Method 2.*

'Error' – ·339	Log. . .	9·5302
Latitude, 24° N.	Cosine. .	9·9607
Azimuth, N. 72° 48' W.	Cotangent	9·4909

Example 3, *Method 1.*

Entering Table C with Lat. 20° N., and 'Error' – ·543, we find the Azimuth to be 63°. Being North Latitude and a – 'Error' we name the Azimuth *North.* The Hour-Angle being P.M., the object is *west* of the meridian. Therefore the complete answer is

N. 63° W.

Example 3, *Method 2.*

'Error' – ·543	Log. . .	9·7348
Latitude, 20° N.	Cosine . .	9·9730
Azimuth, N. 62° 58' W.	Cotangent	9·7078

Example 4, *Method 1.*

Entering Table C with Lat. 50° S., and 'Error' – 2'·557, we find the Azimuth to be about 31¼°. Being South Latitude and a − ' Error ' we name the Azimuth *South*. Therefore the complete answer is

S. 31¼° E.

Example 4, *Method 2.*

' Error ' − 2′·557	Log. . .	0·4077
Latitude, 50° N.	Cosine . .	9·8081
Azimuth, S. 31° 19′ E.	Cotangent	10·2158

Should a celestial object be so near the meridian as to make it doubtful whether the Hour-Angle is East or West, the question is very soon settled by an appeal to the sextant. If the object be rising, the Hour-Angle is East; if falling, it is West. Absurdly simple, when you know it!! Isn't it? But it doesn't occur to everyone, notwithstanding.

In the foregoing examples the ' Error ' has been expressed in arc, but the navigator may wish to have its equivalent in time. If so, he has merely to multiply by 4. Taking examples 3 and 4 we have

− ·543	− 2′·557
× 4	× 4
− 2ˢ·172	− 10ˢ·228

The Tables make their bow.

Thus far, by way of introducing the A B C tables to the reader, we have confined ourselves to an exposition of their more *direct* capabilities, such as determining the Azimuth under all circumstances; also the ' Error ' due to working time observations with an incorrect Latitude; but in chapters yet to come it will be shewn how this information can be turned to account in defining a vessel's true position in connection with the mode of treatment of Double and Simultaneous Altitudes, for which sailors are eternally indebted to the late A. C. Johnson, R.N. (" Cloudy Weather " Johnson). His method has deservedly become very popular, and from its simplicity, accuracy, and comparative brevity, is destined to supersede all others of its class. As auxiliaries, Lecky's A B C tables will be found of great value.

They also give Great Circle courses and distances by mere inspection—an advantage not to be sneezed at. (*See* pages 659-661). Nothing can be simpler or more handy. The Tables are now published separately in greatly extended form.

LECKY'S ABC TABLES.

(Entered at Stationers' Hall, September 1st, 1892.)

FORMULÆ USED IN THEIR CONSTRUCTION.

A = Tang. of Lat. × Cotang. of Hour-angle.

EXAMPLE.

Latitude 3° - - - - - -	Tang.	8·7193958	
Hour-angle 1h. 42m. - - -	Cotang.	10·3215039	+
A = 0′·109875 (*vide* p. 436) - - -		= 9·0408997	

B = Tang. of Declin. × Cosec. of Hour-angle.

EXAMPLE.

Declination 3° - - - - -	Tang.	8·7193958	
Hour-angle 1h. 42m. - -	Cosec.	10·3660156	+
B = 0′·121734 (*vide* p. 437) - - -		= 9·0854114	

C = Cotang. of Azim. × Secant of Latitude.

EXAMPLE.

Azimuth 20° - - - - - -	Cotang.	10·4389341	
Latitude 45° - - - - - -	Secant	10·1505150	+
C = 3′·88552 (*vide* p. 447) - -		= 0·5894491	

As stated in Preface, the results were independently checked by other formulæ, of which there are several. It may interest the reader to know that the quantities in C can be taken out of the Traverse Tables by double entry. For example :—

1. With the *Bearing* (20°) as a *Course*, look for, say, 100 in the *Departure* column, and against it in the *Latitude* column will be found a number (274·7), which divided by 100 will give the quantity (2′·747) for Latitude 0°.
2. With *Latitude* (45°) as a *Course*, and against 274·7 in a *Latitude* column, will be found 388·5 in a *Distance* column : this divided by 100 gives C = 3′·885 as above.

Owing to their narrow limits, the Traverse Tables are hardly good enough where minute accuracy is desired, but it is astonishing the number of problems that can be solved by their aid *when you know how.* In the last edition of Raper, the Traverse Tables have been extended to Distance 600, with corresponding Departure and difference of Latitude ; a much needed improvement.

A.—0 HOURS.

Lat.	m. 1	m. 2	m. 3	m. 4	m. 5	m. 6	m. 7	m. 8	m. 9	m. 10	m. 11	m 12	m. 13	m. 14	m. 15
0°	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
1	4.000	2.000	1.333	1.000	.800	.667	.571	.500	.444	.400	.363	.333	.307	.285	.266
2	8.003	4.002	2.668	2.001	1.600	1.334	1.143	1.000	.889	.800	.727	.666	.615	.571	.533
3	12.01	6.005	4.003	3.002	2.402	2.001	1.715	1.501	1.334	1.200	1.091	1.000	.923	.857	.800
4	16.03	8.013	5.342	4.006	3.205	2.670	2.289	2.002	1.780	1.602	1.456	1.334	1.231	1.143	1.067
5	20.05	10.03	6.683	5.012	4.010	3.341	2.864	2.505	2.227	2.004	1.821	1.669	1.541	1.430	1.335
6°	24.09	12.04	8.029	6.021	4.817	4.014	3.440	3.010	2.675	2.407	2.188	2.005	1.851	1.718	1.604
7	28.14	14.07	9.380	7.034	5.627	4.689	4.019	3.516	3.125	2.812	2.556	2.343	2.162	2.008	1.873
8	32.21	16.10	10.74	8.052	6.441	5.367	4.600	4.025	3.577	3.219	2.926	2.682	2.475	2.298	2.144
9	36.30	18.15	12.10	9.074	7.259	6.048	5.184	4.536	4.031	3.628	3.297	3.022	2.789	2.590	2.417
10	40.41	20.21	13.47	10.10	8.081	6.734	5.771	5.049	4.488	4.039	3.671	3.364	3.105	2.883	2.690
11°	44.55	22.27	14.85	11.14	8.908	7.423	6.362	5.566	4.947	4.452	4.047	3.709	3.423	3.178	2.966
12	48.71	24.36	16.24	12.18	9.741	8.117	6.957	6.087	5.410	4.868	4.425	4.056	3.743	3.475	3.243
13	52.91	26.45	17.64	13.23	10.58	8.817	7.556	6.611	5.876	5.288	4.806	4.405	4.066	3.775	3.522
14	57.14	28.57	19.05	14.28	11.43	9.521	8.161	7.140	6.346	5.711	5.191	4.757	4.391	4.076	3.804
15	61.41	30.70	20.47	15.35	12.28	10.23	8.770	7.673	6.820	6.137	5.578	5.113	4.719	4.381	4.088
16°	65.72	32.86	21.90	16.43	13.14	10.95	9.385	8.211	7.298	6.568	5.970	5.472	5.050	4.688	4.375
17	70.07	35.03	23.35	17.52	14.01	11.68	10.01	8.755	7.781	7.002	6.365	5.834	5.384	4.999	4.665
18	74.47	37.23	24.82	18.61	14.89	12.41	10.63	9.304	8.270	7.442	6.764	6.200	5.722	5.312	4.957
19	78.91	39.46	26.30	19.73	15.78	13.15	11.27	9.860	8.764	7.886	7.168	6.570	6.064	5.630	5.253
20	83.42	41.71	27.80	20.85	16.68	13.90	11.91	10.42	9.264	8.336	7.577	6.945	6.410	5.951	5.553
21°	87.97	43.99	29.32	21.99	17.59	14.66	12.56	10.99	9.770	8.792	7.992	7.325	6.760	6.276	5.857
22	92.60	46.30	30.86	23.15	18.52	15.43	13.22	11.57	10.28	9.254	8.411	7.709	7.115	6.606	6.164
23	97.28	48.64	32.43	24.32	19.45	16.21	13.89	12.16	10.80	9.722	8.837	8.099	7.475	6.940	6.476
24	102.0	51.02	34.01	25.51	20.40	17.00	14.57	12.75	11.33	10.20	9.269	8.495	7.841	7.279	6.793
25	106.9	53.43	35.62	26.71	21.37	17.81	15.26	13.35	11.87	10.68	9.708	8.897	8.212	7.624	7.115
26°	111.8	55.89	37.26	27.94	22.35	18.63	15.96	13.97	12.41	11.17	10.15	9.307	8.589	7.974	7.441
27	116.8	58.39	38.92	29.19	23.35	19.46	16.68	14.59	12.97	11.67	10.61	9.722	8.973	8.331	7.774
28	121.9	60.93	40.62	30.46	24.37	20.31	17.40	15.23	13.53	12.18	11.07	10.15	9.364	8.693	8.112
29	127.0	63.52	42.34	31.76	25.40	21.17	18.14	15.87	14.11	12.70	11.54	10.58	9.762	9.063	8.457
30	132.3	66.16	44.10	33.08	26.46	22.05	18.90	16.53	14.69	13.22	12.02	11.02	10.17	9.440	8.809
31°	137.7	68.85	45.90	34.42	27.54	22.95	19.67	17.21	15.29	13.76	12.51	11.47	10.58	9.824	9.167
32	143.2	71.60	47.73	35.80	28.64	23.86	20.45	17.90	15.90	14.31	13.01	11.92	11.00	10.22	9.534
33	148.8	74.41	49.61	37.21	29.76	24.80	21.26	18.60	16.53	14.87	13.52	12.39	11.44	10.62	9.908
34	154.6	77.29	51.53	38.64	30.91	25.76	22.08	19.32	17.17	15.45	14.04	12.87	11.88	11.03	10.29
35	160.5	80.24	53.49	40.11	32.09	26.74	22.92	20.05	17.82	16.04	14.58	13.36	12.33	11.45	10.68
36°	166.5	83.25	55.50	41.62	33.30	27.75	23.78	20.80	18.49	16.64	15.13	13.86	12.79	11.88	11.08
37	172.7	86.35	57.56	43.17	34.53	28.78	24.66	21.58	19.18	17.26	15.69	14.38	13.27	12.32	11.50
38	179.1	89.53	59.68	44.76	35.81	29.84	25.57	22.37	19.89	17.89	16.27	14.91	13.76	12.77	11.92
39	185.6	92.79	61.86	46.39	37.11	30.92	26.50	23.19	20.61	18.55	16.86	15.45	14.26	13.24	12.35
40	192.3	96.15	64.10	48.07	38.46	32.04	27.46	24.03	21.36	19.22	17.47	16.01	14.78	13.72	12.80
41°	199.2	99.61	66.40	49.81	39.84	33.20	28.45	24.89	22.12	19.91	18.10	16.59	15.31	14.21	13.26
42	206.4	103.2	68.78	51.58	41.26	34.39	29.47	25.78	22.92	20.62	18.75	17.18	15.86	14.72	13.74
43	213.7	106.9	71.23	53.42	42.74	35.61	30.52	26.70	23.73	21.36	19.41	17.79	16.42	15.25	14.23
44	221.3	110.7	73.77	55.32	44.26	36.88	31.61	27.66	24.58	22.12	20.10	18.43	17.01	15.79	14.73
45	229.2	114.6	76.39	57.29	45.83	38.19	32.73	28.64	25.45	22.90	20.82	19.08	17.61	16.35	15.26
46°	237.3	118.7	79.10	59.33	47.46	39.55	33.89	29.66	26.36	23.72	21.56	19.76	18.24	16.93	15.80
47	245.8	122.9	81.92	61.44	49.15	40.95	35.10	30.71	27.29	24.56	22.33	20.46	18.89	17.53	16.36
48	254.5	127.3	84.84	63.63	50.90	42.41	36.35	31.80	28.27	25.44	23.12	21.19	19.56	18.16	16.94
49	263.6	131.8	87.88	65.91	52.72	43.93	37.65	32.94	29.28	26.35	23.95	21.95	20.26	18.81	17.55
50	273.1	136.6	91.04	68.28	54.62	45.51	39.01	34.13	30.33	27.30	24.81	22.74	20.99	19.49	18.18
51°	283.0	141.5	94.33	70.75	56.59	47.16	40.42	35.36	31.43	28.28	25.71	23.56	21.75	20.19	18.84
52	293.3	146.7	97.77	73.33	58.66	48.88	41.89	36.66	32.58	29.32	26.65	24.42	22.54	20.93	19.53
53	304.1	152.1	101.4	76.02	60.82	50.68	43.43	38.01	33.78	30.39	27.63	25.32	23.37	21.70	20.25
54	315.4	157.7	105.1	78.85	63.08	52.56	45.05	39.42	35.03	31.52	28.65	26.26	24.24	22.50	21.00
55	327.3	163.6	109.1	81.81	65.45	54.54	46.74	40.89	36.35	32.71	29.73	27.25	25.15	23.35	21.79
56°	339.8	169.9	113.3	84.93	67.94	56.62	48.52	42.45	37.73	33.96	30.87	28.29	26.11	24.24	22.62
57	352.9	176.5	117.6	88.22	70.57	58.81	50.40	44.10	39.19	35.27	32.06	29.38	27.12	25.18	23.49
58	366.8	183.4	122.2	91.69	73.34	61.11	52.38	45.83	40.73	36.65	33.32	30.54	28.18	26.17	24.42
59	381.4	190.7	127.1	95.35	76.27	63.56	54.47	47.66	42.36	38.12	34.65	31.76	29.31	27.21	25.39
60	397.0	198.5	132.3	99.23	79.38	66.14	56.69	49.60	44.08	30.67	36.06	33.05	30.50	28.32	26.43
	m. 59	m. 58	m. 57	m. 56	m. 55	m. 54	m. 53	m. 52	m, 51	m. 50	m. 49	m. 48	m. 47	m. 46	m. 45

A.—11 HOURS.

B.—0 HOURS.

Dec.	m. 1	m. 2	m 3	m. 4	m. 5	m. 6	m. 7	m. 8	m. 9	m. 10	m. 11	m 12	m. 13	m. 14	m. 15
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	4·000	2·000	1·334	1·000	·800	·667	·572	·500	·445	·400	·364	·334	·308	·286	.267
2	8·003	4·002	2·668	2·001	1·601	1·334	1·143	1·001	·889	·801	·728	·667	·616	·572	·534
3	12·01	6·006	4·004	3·003	2·402	2·002	1·716	1·502	1·335	1·201	1·092	1·001	·924	·858	·801
4	16·03	8·013	5·342	4·007	3·205	2·671	2·290	2·004	1·781	1·603	1·457	1·336	1·233	1·145	1·069
5	20·05	10·03	6·684	5·013	4·011	3·342	2·865	2·507	2·228	2·006	1 824	1·672	1·543	1·433	1·338
6°	24·09	12·04	8·030	6·022	4·818	4·015	3·442	3·012	2·677	2·410	2·191	2·008	1·854	1·722	1·607
7	28·14	14·07	9·380	7·035	5·628	4·691	4·021	3·518	3·127	2·815	2·559	2·346	2·166	2·011	1·877
8	32·21	16·10	10·74	8·053	6·442	5·369	4·602	4·027	3·580	3·222	2·929	2·685	2·479	2·302	2·149
9	36·30	18·15	12.10	9·075	7·260	6·051	5·186	4·538	4·034	3·631	3·301	3·026	2·794	2·594	2·422
10	40·41	20·21	13.47	10·10	8·083	6·736	5·774	5·052	4·491	4·042	3·675	3·369	3·110	2·888	2·696
11°	44·55	22·27	14·85	11·14	8·910	7·426	6·365	5·570	4·951	4·456	4·051	3·714	3·429	3·184	2·972
12	48·71	24·36	16·24	12·18	9·744	8·120	6·960	6·091	5·414	4·873	4·430	4·061	3·749	3·482	3·250
13	52·91	26·46	17·64	13·23	10·58	8·820	7·560	6·615	5·881	5·293	4·812	4·411	4·072	3·782	3·530
14	57·14	28·57	19·05	14·29	11·43	9·525	8·164	7·144	6·351	5·716	5·197	4·764	4·398	4·084	3·812
15	61·41	30·71	20·47	15·35	12·28	10·24	8·774	7·678	6·825	6·143	5·585	5·120	4·726	4·389	4·097
16°	65·72	32·86	21·91	16·43	13·14	10·95	9·390	8·216	7·304	6·574	5·977	5·479	5·058	4·697	4·384
17	70·07	35·03	23·36	17·52	14·01	11·68	10·01	8·760	7·787	7·009	6·372	5·842	5·393	5·008	4·675
18	74·46	37·23	24·82	18·62	14·89	12·41	10·64	9·310	8·276	7·449	6·772	6·208	5·731	5·322	4·968
19	78·91	39·46	26·31	19·73	15·78	13·15	11·28	9·866	8·770	7·894	7·177	6·579	6·074	5·640	5·265
20	83·42	41·71	27·81	20·86	16·68	13·90	11·92	10·43	9·271	8·344	7·586	6·954	6·420	5·962	5·565
21°	87·98	43·99	29·33	21·99	17·60	14·66	12·57	11·00	9·778	8·800	8·001	7·335	6·771	6·288	5·869
22	92·60	46·30	30·87	23·15	18·52	15·43	13·23	11·58	10·29	9·263	8·421	7·720	7·127	6·618	6·177
23	97·28	48·64	32·43	24·32	19·46	16·22	13·90	12·16	10·81	9·731	8·847	8·110	7·487	6·953	6·490
24	102·0	51·02	34·01	25·51	20·41	17·01	14·58	12·76	11·34	10·21	9.280	8·507	7·853	7·293	6·807
25	106·9	53·44	35·62	26·72	21·38	17·81	15·27	13·36	11·88	10·69	9·719	8·910	8·225	7·638	7·130
26°	111·8	55·89	37·26	27·95	22·36	18·63	15·97	13·98	12·42	11·18	10·17	9·319	8·603	7·989	7·457
27	116·8	58·39	38·93	29·20	23·36	19·46	16·68	14·00	12·98	11·68	10·62	9·736	8·987	8·346	7·791
28	121·9	60·93	40·62	30·47	24·37	20·31	17·41	15·24	13·54	12·19	11·08	10·16	9·379	8·710	8·130
29	127·0	63·52	42·35	31·76	25·41	21·18	18·15	15·88	14·12	12·71	11·55	10·59	9·777	9·080	8·475
	m. 59	m. 58	m. 57	m. 56	m. 55	m. 54	m. 53	m. 52	m. 51	m. 50	m. 49	m 48	m. 47	m. 46	m. 45

B.—11 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—0 HOURS.

Stars.	m. 1	m. 2	m. 3	m 4	m. 5	m. 6	m. 7	m. 8	m. 9	m. 10	m. 11	m. 12	m. 13	m. 14	m. 15
Fomalhaut	133·1	66·57	44·38	33·29	26·63	22·19	19·02	16·65	14·80	13·32	12·11	11·10	10·25	9·516	8·883
Castor . .	143·8	71·91	47·94	35·96	28·76	23·97	20·55	17·98	15·98	14·39	13·08	11·99	11·07	10·28	9·594
α Columbæ .	155·3	77·65	51·76	38·82	31·06	25·88	22·19	19·42	17·26	15·53	14·12	12·95	11·95	11·10	10·36
Vega. . .	183·5	91·77	61·18	45·88	36·71	30·59	26·22	22·95	20·40	18·36	16·69	15·30	14·13	13·12	12·24
α Phœnicis .	212·6	106·3	70·87	53·15	42·52	35·44	30·38	26·58	23·63	21·27	19·33	17·72	16·36	15·19	14·18
α Cygni . .	228·6	114·3	76·19	57·14	45·71	38·10	32·66	28·57	25·40	22·86	20·79	19·05	17·59	16·34	15·25
Capella . .	236·5	118·3	78·84	59·13	47·30	39·42	33·79	29·57	26·28	23·66	21·51	19·72	18·20	16·90	15·78
α Gruis . .	249·7	124·8	83·23	62·42	49·94	41·62	35·67	31·22	27·75	24·98	22·71	20·82	19·22	17·84	16·66
α Persei .	268·5	134·2	89·49	67·12	53·70	44·75	38·36	33·56	29·84	26·85	24·41	22·38	20·66	19·19	17·91
Benetnasch	271·3	135·6	90·43	67·82	54·26	45·22	38·76	33·92	30·15	27·14	24·67	22·62	20·88	19·39	18·10
Canopus .	300·2	150·1	100·1	75·05	60·04	50·03	42·89	37·53	33·36	30·03	27·30	25·03	23·10	21·45	20·03
α Cassiopeiæ	339·7	169·9	113·2	84·94	67·95	56·63	48·54	42·47	37·76	33·98	30·90	28·32	26·15	24·28	22·66
α Pavonis. .	353·7	176·9	117·9	88·43	70·75	58·96	50·54	44·22	39·31	35·38	32·17	29·49	27·22	25·28	23·60
Achernar .	363·2	181·6	121·1	90·81	72·65	60·55	51·90	45·41	40·37	36·33	33·03	30·28	27·96	25·96	24·23
ι Argûs . .	379·2	189·6	126·4	94·80	75·84	63·20	54·18	47·41	42·14	37·93	34·48	31·61	29·18	27·10	25·30
β Centauri .	395·2	197·6	131·7	98·80	79·04	65·87	56·46	49·41	43·92	39·53	35·94	32·95	30·41	28·24	26·36
Dubhe . .	436·3	218·2	145·4	109·1	87·27	72·72	62·34	54·55	48·49	43·64	39·68	36·37	33·58	31·18	29·11
α_1 Crucis . .	441·0	220·5	147·0	110·3	88·21	73·51	63·02	55·14	49·02	44·12	40·11	36·77	33·94	31·52	29·42
α Tri. Austr.	592·3	296·1	197·4	148·1	118·5	98·72	84·62	74·05	65·83	59·25	53·86	49·38	45·58	42·33	39·51
β Urs. Min. .	829·7	414·8	276·6	207·4	166·0	138·3	118·5	103·7	92·21	83·00	75·46	69·17	63·86	59·30	55·35
	m. 59	m. 58	m. 57	m. 56	m. 55	m. 54	m. 53	m. 52	m. 51	m. 50	m. 49	m. 48	m. 47	m 46	m. 45

B.—11 HOURS.

A.—0 HOURS.

Lat.	m. 1	m. 2	m. 3	m. 4	m. 5	m. 6	m. 7	m. 8	m. 9	m. 10	m. 11	m. 12	m. 13	m. 14	m. 15
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	4·000	2·000	1·333	1·000	·800	·667	·571	·500	·444	·400	·363	·333	·307	·285	·266
2	8·003	4·002	2·668	2·001	1·600	1·334	1·143	1·000	·889	·800	·727	·666	·615	·571	·533
3	12·01	6·005	4·003	3·002	2·402	2·001	1·715	1·501	1·334	1·200	1·091	1·000	·923	·857	·800
4	16·03	8·013	5·342	4·006	3·205	2·670	2·289	2·002	1·780	1·602	1·456	1·334	1·231	1·143	1·067
5	20·05	10·03	6·683	5·012	4·010	3·341	2·864	2·505	2·227	2·004	1·821	1·669	1·541	1·430	1·335
6°	24·09	12·04	8·029	6·021	4·817	4·014	3·440	3·010	2·675	2·407	2·188	2·005	1·851	1·718	1·604
7	28·14	14·07	9·380	7·034	5·627	4·689	4·019	3·516	3·125	2·812	2·556	2·343	2·162	2·008	1·873
8	32·21	16·10	10·74	8·052	6·441	5·367	4·600	4·025	3·577	3·219	2·926	2·682	2·475	2·298	2·144
9	36·30	18·15	12·10	9·074	7·259	6·048	5·184	4·536	4·031	3·628	3·297	3·022	2·789	2·590	2·417
10	40·41	20·21	13·47	10·10	8·081	6·734	5·771	5·049	4·488	4·039	3·671	3·364	3·105	2·883	2·690
11°	44·55	22·27	14·85	11·14	8·908	7·423	6·362	5·566	4·947	4·452	4·047	3·709	3·423	3·178	2·966
12	48·71	24·36	16·24	12·18	9·741	8·117	6·957	6·087	5·410	4·868	4·425	4·056	3·743	3·475	3·243
13	52·91	26·45	17·64	13·23	10·58	8·817	7·556	6·611	5·876	5·288	4·806	4·405	4·066	3·775	3·522
14	57·14	28·57	19·05	14·28	11·43	9·521	8·161	7·140	6·346	5·711	5·191	4·757	4·391	4·076	3·804
15	61·41	30·70	20·47	15·35	12·28	10·23	8·770	7·673	6·820	6·137	5·578	5·113	4·719	4·381	4·088
16°	65·72	32·86	21·90	16·43	13·14	10·95	9·385	8·211	7·298	6·568	5·970	5·472	5·050	4·688	4·375
17	70·07	35·03	23·35	17·52	14·01	11·68	10·01	8·755	7·781	7·002	6·365	5·834	5·384	4·999	4·665
18	74·47	37·23	24·82	18·61	14·89	12·41	10·63	9·304	8·270	7·442	6·764	6·200	5·722	5·312	4·957
19	78·91	39·46	26·30	19·73	15·78	13·15	11·27	9·860	8·764	7·886	7·168	6·570	6·064	5·630	5·253
20	83·42	41·71	27·80	20·85	16·68	13·90	11·91	10·42	9·264	8·336	7·577	6·945	6·410	5·951	5·553
21°	87·97	43·99	29·32	21·99	17·59	14·66	12·56	10·99	9·770	8·792	7·992	7·325	6·760	6·276	5·857
22	92·60	46·30	30·86	23·15	18·52	15·43	13·22	11·57	10·28	9·254	8·411	7·709	7·115	6·606	6·164
23	97·28	48·64	32·43	24·32	19·45	16·21	13·89	12·16	10·80	9·722	8·837	8·099	7·475	6·940	6·476
24	102·0	51·02	34·01	25·51	20·40	17·00	14·57	12·75	11·33	10·20	9·269	8·495	7·841	7·279	6·793
25	106·9	53·43	35·62	26·71	21·37	17·81	15·26	13·35	11·87	10·68	9·708	8·897	8·212	7·624	7·115
26°	111·8	55·89	37·26	27·94	22·35	18·63	15·96	13·97	12·41	11·17	10·15	9·307	8·589	7·974	7·441
27	116·8	58·39	38·92	29·19	23·35	19·46	16·68	14·59	12·97	11·67	10·61	9·722	8·973	8·331	7·774
28	121·9	60·93	40·62	30·46	24·37	20·31	17·40	15·23	13·53	12·18	11·07	10·15	9·364	8·693	8·112
29	127·0	63·52	42·34	31·76	25·40	21·17	18·14	15·87	14·11	12·70	11·54	10·58	9·762	9·063	8·457
30	132·3	66·16	44·10	33·08	26·46	22·05	18·90	16·53	14·69	13·22	12·02	11·02	10·17	9·440	8·809
31°	137·7	68·85	45·90	34·42	27·54	22·95	19·67	17·21	15·29	13·76	12·51	11·47	10·58	9·824	9·167
32	143·2	71·60	47·73	35·80	28·64	23·86	20·45	17·90	15·90	14·31	13·01	11·92	11·00	10·22	9·534
33	148·8	74·41	49·61	37·21	29·76	24·80	21·26	18·60	16·53	14·87	13·52	12·39	11·44	10·62	9·908
34	154·6	77·29	51·53	38·64	30·91	25·76	22·08	19·32	17·17	15·45	14·04	12·87	11·88	11·03	10·29
35	160·5	80·24	53·49	40·11	32·09	26·74	22·92	20·05	17·82	16·04	14·58	13·36	12·33	11·45	10·68
36°	166·5	83·25	55·50	41·62	33·30	27·75	23·78	20·80	18·49	16·64	15·13	13·86	12·79	11·88	11·08
37	172·7	86·35	57·56	43·17	34·53	28·78	24·66	21·58	19·18	17·26	15·69	14·38	13·27	12·32	11·50
38	179·1	89·53	59·68	44·76	35·81	29·84	25·57	22·37	19·89	17·89	16·27	14·91	13·76	12·77	11·92
39	185·6	92·79	61·86	46·39	37·11	30·92	26·50	23·19	20·61	18·55	16·86	15·45	14·26	13·24	12·35
40	192·3	96·15	64·10	48·07	38·46	32·04	27·46	24·03	21·36	19·22	17·47	16·01	14·78	13·72	12·80
41°	199·2	99·61	66·40	49·81	39·84	33·20	28·45	24·89	22·12	19·91	18·10	16·59	15·31	14·21	13·26
42	206·4	103·2	68·78	51·58	41·26	34·39	29·47	25·78	22·92	20·62	18·75	17·18	15·86	14·72	13·74
43	213·7	106·9	71·23	53·42	42·74	35·61	30·52	26·70	23·73	21·36	19·41	17·79	16·42	15·25	14·23
44	221·3	110·7	73·77	55·32	44·26	36·88	31·61	27·66	24·58	22·12	20·10	18·43	17·01	15·79	14·73
45	229·2	114·6	76·39	57·29	45·83	38·19	32·73	28·64	25·45	22·90	20·82	19·08	17·61	16·35	15·26
46°	237·3	118·7	79·10	59·33	47·46	39·55	33·89	29·66	26·36	23·72	21·56	19·76	18·24	16·93	15·80
47	245·8	122·9	81·92	61·44	49·15	40·95	35·10	30·71	27·29	24·56	22·33	20·46	18·89	17·53	16·36
48	254·5	127·3	84·84	63·63	50·90	42·41	36·35	31·80	28·27	25·44	23·12	21·19	19·56	18·16	16·94
49	263·6	131·8	87·88	65·91	52·72	43·93	37·65	32·94	29·28	26·35	23·95	21·95	20·26	18·81	17·55
50	273·1	136·6	91·04	68·28	54·62	45·51	39·01	34·13	30·33	27·30	24·81	22·74	20·99	19·49	18·18
51°	283·0	141·5	94·33	70·75	56·59	47·16	40·42	35·36	31·43	28·28	25·71	23·56	21·75	20·19	18·84
52	293·3	146·7	97·77	73·33	58·66	48·88	41·89	36·66	32·58	29·32	26·65	24·42	22·54	20·93	19·53
53	304·1	152·1	101·4	76·02	60·82	50·68	43·43	38·01	33·78	30·39	27·63	25·32	23·37	21·70	20·25
54	315·4	157·7	105·1	78·85	63·08	52·56	45·05	39·42	35·03	31·52	28·65	26·26	24·24	22·50	21·00
55	327·3	163·6	109·1	81·81	65·45	54·54	46·74	40·89	36·35	32·71	29·73	27·25	25·15	23·35	21·79
56°	339·8	169·9	113·3	84·93	67·94	56·62	48·52	42·45	37·73	33·96	30·87	28·29	26·11	24·24	22·62
57	352·9	176·5	117·6	88·22	70·57	58·81	50·40	44·10	39·19	35·27	32·06	29·38	27·12	25·18	23·49
58	366·8	183·4	122·2	91·69	73·34	61·11	52·38	45·83	40·73	36·65	33·32	30·54	28·18	26·17	24·42
59	381·4	190·7	127·1	95·35	76·27	63·56	54·47	47·66	42·36	38·12	34·65	31·76	29·31	27·21	25·39
60	397·0	198·5	132·3	99·23	79·38	66·14	56·69	49·60	44·08	39·67	36·06	33·05	30·50	28·32	26·43
	m. 59	m. 58	m. 57	m. 56	m. 55	m. 54	m. 53	m. 52	m. 51	m. 50	m. 49	m. 48	m. 47	m. 46	m. 45

A.—11 HOURS.

B.—0 HOURS.

Dec.	m. 1	m. 2	m. 3	m. 4	m. 5	m. 6	m. 7	m. 8	m. 9	m. 10	m. 11	m. 12	m. 13	m. 14	m. 15
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	4·000	2·000	1·334	1·000	·800	·667	·572	·500	·445	·400	·364	·334	·308	·286	.267
2	8·003	4·002	2·668	2·001	1·601	1·334	1·143	1·001	·889	·801	·728	·667	·616	·572	·534
3	12·01	6·006	4·004	3·003	2·402	2·002	1·716	1·502	1·335	1·201	1·092	1·001	·924	·858	·801
4	16·03	8·013	5·342	4·007	3·205	2·671	2·290	2·004	1·781	1·603	1·457	1·336	1·233	1·145	1·069
5	20·05	10·03	6·684	5·013	4·011	3·342	2·865	2·507	2·228	2·006	1·824	1·672	1·543	1·433	1·338
6°	24·09	12·04	8·030	6·022	4·818	4·015	3·442	3·012	2·677	2·410	2·191	2·008	1·854	1·722	1·607
7	28·14	14·07	9·380	7·035	5·628	4·691	4·021	3·518	3·127	2·815	2·559	2·346	2·166	2·011	1·877
8	32·21	16·10	10·74	8·053	6·442	5·369	4·602	4·027	3·580	3·222	2·929	2·685	2·479	2·302	2·149
9	36·30	18·15	12.10	9·075	7·260	6·051	5·186	4·538	4·034	3·631	3·301	3·026	2·794	2·594	2·422
10	40·41	20·21	13·47	10·10	8·083	6·736	5·774	5·052	4·491	4·042	3·675	3·369	3·110	2·888	2·696
11°	44·55	22·27	14·85	11·14	8·910	7·426	6·365	5·570	4·951	4·456	4·051	3·714	3·429	3·184	2·972
12	48·71	24·36	16·24	12·18	9·744	8·120	6·960	6·091	5·414	4·873	4·430	4·061	3·749	3·482	3·250
13	52·91	26·46	17·64	13·23	10·58	8·820	7·560	6·615	5·881	5·293	4·812	4·411	4·072	3·782	3·530
14	57·14	28·57	19·05	14·29	11·43	9·525	8·164	7·144	6·351	5·716	5·197	4·764	4·398	4·084	3·812
15	61·41	30·71	20·47	15·35	12·28	10·24	8·774	7·678	6·825	6·143	5·585	5·120	4·726	4·389	4·097
16°	65·72	32·86	21·91	16·43	13·14	10·95	9·390	8·216	7·304	6·574	5·977	5·479	5·058	4·697	4·384
17	70·07	35·03	23·36	17·52	14·01	11·68	10·01	8·760	7·787	7·009	6·372	5·842	5·393	5·008	4·675
18	74·46	37·23	24·82	18·62	14·89	12·41	10·64	9·310	8·276	7·449	6·772	6·208	5·731	5·322	4·968
19	78·91	39·46	26·31	19·73	15·78	13·15	11·28	9·866	8·770	7·894	7·177	6·579	6·074	5·640	5·265
20	83·42	41·71	27·81	20·86	16·68	13·90	11·92	10·43	9·271	8·344	7·586	6·954	6·420	5·962	5·565
21°	87·98	43·99	29·33	21·99	17·60	14·66	12·57	11·00	9·778	8·800	8·001	7·335	6·771	6·288	5·869
22	92·60	46·30	30·87	23·15	18·52	15·43	13·23	11·58	10·29	9·263	8·421	7·720	7·127	6·618	6·177
23	97·28	48·64	32·43	24·32	19·46	16·22	13·90	12·16	10·81	9·731	8·847	8·110	7·487	6·953	6·490
24	102·0	51·02	34·01	25·51	20·41	17·01	14·58	12·76	11·34	10·21	9.280	8·507	7·853	7·293	6·807
25	106·9	53·44	35·62	26·72	21·38	17·81	15·27	13·36	11·88	10·69	9·719	8·910	8·225	7·638	7·130
26°	111·8	55·89	37·26	27·95	22·36	18·63	15·97	13·98	12·42	11·18	10·17	9·319	8·603	7·989	7·457
27	116·8	58·39	38·93	29·20	23·36	19·46	16·68	14·60	12·98	11·68	10·62	9·736	8·987	8·346	7·791
28	121·9	60·93	40·62	30·47	24·37	20·31	17·41	15·24	13·54	12·19	11·08	10·16	9·379	8·710	8·130
29	127·0	63·52	42·35	31·76	25·41	21·18	18·15	15·88	14·12	12·71	11·55	10·59	9·777	9·080	8·475
	m. 59	m. 58	m. 57	m. 56	m. 55	m. 54	m. 53	m. 52	m. 51	m. 50	m. 49	m 48	m. 47	m. 46	m. 45

B.—11 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—0 HOURS.

Stars.	m. 1	m. 2	m. 3	m 4	m. 5	m. 6	m. 7	m. 8	m. 9	m. 10	m. 11	m. 12	m. 13	m. 14	m. 15
Fomalhaut	133·1	66·57	44·38	33·29	26·63	22·19	19·02	16·65	14·80	13·32	12·11	11·10	10·25	9·516	8·883
Castor . .	143·8	71·91	47·94	35·96	28·76	23·97	20·55	17·98	15·98	14·39	13·08	11·99	11·07	10·28	9·594
α Columbæ .	155·3	77·65	51·76	38·82	31·06	25·88	22·19	19·42	17·26	15·53	14·12	12·95	11·95	11·10	10·36
Vega. . .	183·5	91·77	61·18	45·88	36·71	30·59	26·22	22·95	20·40	18·36	16·69	15·30	14·13	13·12	12·24
α Phœnicis .	212·6	106·3	70·87	53·15	42·52	35·44	30·38	26·58	23·63	21·27	19·33	17·72	16·36	15·19	14·18
α Cygni . .	228·6	114·3	76·19	57·14	45·71	38·10	32·66	28·57	25·40	22·86	20·79	19·05	17·59	16·34	15·25
Capella . .	236·5	118·3	78·84	59·13	47·30	39·42	33·79	29·57	26·28	23·66	21·51	19·72	18·20	16·90	15·78
α Gruis . .	249·7	124·8	83·23	62·42	49·94	41·62	35·67	31·22	27·75	24·98	22·71	20·82	19·22	17·84	16·66
α Persei . .	268·5	134·2	89·49	67·12	53·70	44·75	38·36	33·56	29·84	26·85	24·41	22·38	20·66	19·19	17·91
Benetnasch	271·3	135·6	90·43	67·82	54·26	45·22	38·76	33·92	30·15	27·14	24·67	22·62	20·88	19·39	18·10
Canopus .	300·2	150·1	100·1	75·05	60·04	50·03	42·89	37·53	33·36	30·03	27·30	25·03	23·10	21·45	20·03
α Cassiopeiæ .	339·7	169·9	113·2	84·94	67·95	56·63	48·54	42·47	37·76	33·98	30·90	28·32	26·15	24·28	22·66
α Pavonis. .	353·7	176·9	117·9	88·43	70·75	58·96	50·54	44·22	39·31	35·38	32·17	29·49	27·22	25·28	23·60
Achernar .	363·2	181·6	121·1	90·81	72·65	60·55	51·90	45·41	40·37	36·33	33·03	30·28	27·96	25·96	24·23
ι Argûs . .	379·2	189·6	126·4	94·80	75·84	63·20	54·18	47·41	42·14	37·93	34·48	31·61	29·18	27·10	25·30
β Centauri .	395·2	197·6	131·7	98·80	79·04	65·87	56·46	49·41	43·92	39·53	35·94	32·95	30·41	28·24	26·36
Dubhe . .	436·3	218·2	145·4	109·1	87·27	72·72	62·34	54·55	48·49	43·64	39·68	36·37	33·58	31·18	29·11
α_1 Crucis . .	441·0	220·5	147·0	110·3	88·21	73·51	63·02	55·14	49·02	44·12	40·11	36·77	33·94	31·52	29·42
α Tri. Austr.	592·3	296·1	197·4	148·1	118·5	98·72	84·62	74·05	65·83	59·25	53·86	49·38	45·58	42·33	39·51
β Urs. Min. .	829·7	414·8	276·6	207·4	166·0	138·3	118·5	103·7	92·21	83·00	75·46	69·17	63·86	59·30	55·35
	m. 59	m. 58	m. 57	m. 56	m. 55	m. 54	m. 53	m. 52	m. 51	m. 50	m. 49	m. 48	m. 47	m 46	m. 45

B.—11 HOURS.

A.—0 HOURS.

Lat.	m. 16	m. 17	m. 18	m. 19	m. 20	m. 21	m. 22	m. 23	m. 24	m. 25	m. 26	m. 27	m. 28	m. 29	m. 30
0°	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
1	.250	.235	.222	.210	.200	.190	.181	.173	.166	.159	.153	.148	.142	.137	.133
2	.499	.470	.444	.420	.399	.380	.363	.347	.332	.319	.307	.295	.284	.275	.265
3	.749	.705	.666	.631	.599	.570	.544	.521	.499	.479	.460	.443	.427	.412	.398
4	1.000	.941	.889	.842	.799	.761	.726	.694	.665	.639	.614	.591	.570	.550	.531
5	1.251	1.177	1.112	1.053	1.000	.952	.909	.869	.832	.799	.768	.739	.713	.688	.665
6°	1.503	1.414	1.335	1.265	1.201	1.144	1.092	1.044	1.000	.960	.923	.888	.856	.826	.798
7	1.756	1.652	1.560	1.478	1.403	1.336	1.275	1.219	1.168	1.121	1.078	1.037	1.000	.965	.933
8	2.010	1.891	1.786	1.691	1.606	1.530	1.460	1.396	1.337	1.283	1.234	1.187	1.145	1.105	1.068
9	2.265	2.131	2.012	1.906	1.810	1.724	1.645	1.573	1.507	1.446	1.390	1.338	1.290	1.245	1.203
10	2.522	2.373	2.240	2.122	2.015	1.919	1.831	1.751	1.678	1.610	1.548	1.490	1.436	1.386	1.339
11°	2.780	2.616	2.470	2.339	2.222	2.115	2.019	1.930	1.849	1.775	1.706	1.642	1.583	1.528	1.476
12	3.040	2.860	2.701	2.558	2.430	2.313	2.207	2.111	2.022	1.941	1.866	1.796	1.731	1.671	1.615
13	3.302	3.107	2.933	2.778	2.639	2.513	2.398	2.293	2.197	2.108	2.026	1.951	1.880	1.815	1.754
14	3.566	3.355	3.168	3.001	2.850	2.713	2.589	2.476	2.372	2.277	2.188	2.107	2.031	1.960	1.894
15	3.832	3.606	3.405	3.225	3.063	2.916	2.783	2.661	2.549	2.447	2.352	2.264	2.182	2.106	2.035
16°	4.101	3.859	3.643	3.451	3.278	3.121	2.978	2.848	2.728	2.618	2.517	2.423	2.335	2.254	2.178
17	4.372	4.114	3.885	3.679	3.495	3.327	3.175	3.036	2.909	2.792	2.683	2.583	2.490	2.403	2.322
18	4.647	4.372	4.128	3.910	3.714	3.536	3.374	3.227	3.091	2.967	2.852	2.745	2.646	2.554	2.468
19	4.924	4.633	4.375	4.144	3.936	3.747	3.576	3.420	3.276	3.144	3.022	2.909	2.804	2.707	2.615
20	5.205	4.898	4.625	4.380	4.160	3.961	3.780	3.615	3.463	3.323	3.195	3.075	2.964	2.861	2.765
21°	5.490	5.166	4.877	4.620	4.388	4.178	3.987	3.812	3.652	3.505	3.369	3.243	3.126	3.017	2.916
22	5.778	5.437	5.134	4.862	4.618	4.397	4.196	4.012	3.844	3.689	3.546	3.414	3.291	3.176	3.069
23	6.070	5.712	5.393	5.108	4.852	4.620	4.408	4.215	4.039	3.876	3.726	3.586	3.457	3.337	3.224
24	6.367	5.991	5.657	5.358	5.089	4.845	4.624	4.422	4.236	4.065	3.908	3.762	3.626	3.500	3.382
25	6.669	6.275	5.925	5.612	5.330	5.075	4.843	4.631	4.437	4.258	4.093	3.940	3.798	3.666	3.542
26°	6.975	6.563	6.197	5.870	5.575	5.308	5.065	4.844	4.640	4.453	4.281	4.121	3.972	3.834	3.705
27	7.287	6.856	6.474	6.132	5.824	5.545	5.292	5.060	4.848	4.652	4.472	4.305	4.150	4.005	3.870
28	7.604	7.155	6.756	6.399	6.077	5.787	5.522	5.280	5.059	4.855	4.667	4.492	4.330	4.180	4.039
29	7.927	7.459	7.043	6.671	6.336	6.033	5.757	5.505	5.274	5.061	4.865	4.683	4.514	4.357	4.210
30	8.256	7.769	7.336	6.948	6.599	6.283	5.996	5.734	5.493	5.272	5.067	4.878	4.702	4.538	4.385
31°	8.593	8.086	7.635	7.231	6.868	6.539	6.240	5.967	5.717	5.486	5.274	5.077	4.894	4.723	4.564
32	8.936	8.409	7.940	7.520	7.142	6.800	6.490	6.206	5.945	5.706	5.484	5.279	5.089	4.912	4.740
33	9.287	8.739	8.252	7.815	7.423	7.067	6.744	6.449	6.179	5.930	5.700	5.487	5.289	5.105	4.933
34	9.646	9.077	8.570	8.117	7.710	7.341	7.005	6.699	6.418	6.159	5.920	5.699	5.493	5.302	5.123
35	10.01	9.422	8.897	8.427	8.003	7.620	7.272	6.954	6.662	6.394	6.146	5.916	5.703	5.504	5.319
36°	10.39	9.777	9.232	8.744	8.304	7.907	7.545	7.215	6.913	6.634	6.377	6.139	5.917	5.711	5.519
37	10.78	10.14	9.575	9.069	8.613	8.201	7.826	7.484	7.170	6.881	6.614	6.367	6.137	5.923	5.724
38	11.17	10.51	9.927	9.402	8.930	8.503	8.114	7.759	7.433	7.134	6.857	6.601	6.363	6.141	5.934
39	11.58	10.90	10.29	9.745	9.256	8.813	8.410	8.042	7.705	7.394	7.107	6.842	6.595	6.365	6.151
40	12.00	11.29	10.66	10.10	9.591	9.132	8.714	8.333	7.984	7.662	7.365	7.090	6.834	6.596	6.374
41°	12.43	11.70	11.05	10.46	9.936	9.460	9.028	8.633	8.271	7.937	7.630	7.345	7.080	6.833	6.603
42	12.88	12.12	11.44	10.84	10.29	9.799	9.351	8.942	8.567	8.222	7.903	7.607	7.333	7.078	6.839
43	13.34	12.55	11.85	11.22	10.66	10.15	9.685	9.261	8.872	8.515	8.185	7.879	7.595	7.330	7.083
44	13.81	12.99	12.27	11.62	11.04	10.51	10.03	9.590	9.188	8.818	8.476	8.159	7.865	7.591	7.335
45	14.30	13.46	12.71	12.03	11.43	10.88	10.39	9.931	9.514	9.131	8.777	8.449	8.144	7.861	7.596
46°	14.81	13.93	13.16	12.46	11.84	11.27	10.75	10.28	9.852	9.455	9.089	8.749	8.434	8.140	7.866
47	15.34	14.43	13.63	12.91	12.26	11.67	11.14	10.65	10.20	9.792	9.412	9.060	8.734	8.430	8.145
48	15.88	14.95	14.11	13.37	12.69	12.09	11.53	11.03	10.57	10.14	9.748	9.384	9.045	8.730	8.430
49	16.45	15.48	14.62	13.84	13.15	12.52	11.95	11.42	10.95	10.50	10.10	9.719	9.369	9.043	8.738
50	17.04	16.04	15.14	14.34	13.62	12.97	12.38	11.84	11.34	10.88	10.46	10.07	9.706	9.368	9.052
51°	17.66	16.62	15.69	14.86	14.11	13.44	12.82	12.26	11.75	11.28	10.84	10.43	10.06	9.707	9.380
52	18.30	17.22	16.26	15.40	14.63	13.93	13.29	12.71	12.18	11.69	11.23	10.81	10.42	10.00	9.722
53	18.98	17.86	16.86	15.97	15.17	14.44	13.78	13.18	12.63	12.12	11.65	11.21	10.81	10.43	10.08
54	19.68	18.52	17.49	16.56	15.73	14.98	14.29	13.67	13.10	12.57	12.08	11.63	11.21	10.82	10.45
55	20.42	19.22	18.15	17.19	16.32	15.54	14.83	14.18	13.59	13.04	12.53	12.07	11.63	11.23	10.85
56°	21.20	19.95	18.84	17.84	16.95	16.13	15.40	14.72	14.11	13.54	13.01	12.53	12.07	11.65	11.26
57	22.02	20.72	19.57	18.53	17.60	16.76	15.99	15.29	14.65	14.06	13.52	13.01	12.54	12.10	11.70
58	22.89	21.54	20.33	19.26	18.29	17.42	16.62	15.89	15.23	14.61	14.05	13.52	13.03	12.58	12.16
59	23.80	22.40	21.15	20.03	19.02	18.11	17.28	16.53	15.83	15.20	14.61	14.06	13.55	13.08	12.64
60	24.77	23.31	22.01	20.84	19.80	18.85	17.99	17.20	16.48	15.82	15.20	14.63	14.11	13.62	13.16
	m. 44	m. 43	m. 42	m. 41	m. 40	m. 39	m. 38	m. 37	m. 36	m. 35	m. 34	m. 33	m. 32	m. 31	m. 30

A.—11 HOURS.

B.—O HOURS.

Dec.	m. 16	m. 17	m. 18	m. 19	m. 20	m. 21	m. 22	m. 23	m. 24	m. 25	m. 26	m. 27	m. 28	m. 29	m. 30
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·250	·236	·222	·211	·200	·191	·182	·174	·167	·160	·154	·149	·143	·138	·134
2	·501	·471	·445	·422	·401	·382	·364	·349	·334	·321	·308	·297	·287	·277	·268
3	·751	·707	·668	·633	·601	·573	·547	·523	·501	·481	·463	·446	·430	·415	·402
4	1·002	·944	·891	·844	·802	·764	·730	·698	·669	·642	·618	·595	·574	·554	·536
5	1·254	1·181	1·115	1·057	1·004	·956	·913	·873	·837	·804	·773	·744	·718	·693	·670
6°	1·507	1·418	1·340	1·269	1·206	1·149	1·097	1·049	1·006	·965	·928	·894	·862	·833	·805
7	1·760	1·657	1·565	1·483	1·409	1·342	1·281	1·226	1·175	1·128	1·085	1·045	1·008	·973	·941
8	2·015	1·896	1·791	1·697	1·613	1·536	1·466	1·403	1·345	1·291	1·241	1·196	1·153	1·114	1·077
9	2·271	2·137	2·019	1·913	1·817	1·731	1·652	1·581	1·515	1·455	1·399	1·348	1·300	1·255	1·213
10	2·528	2·379	2·247	2·129	2·023	1·927	1·840	1·760	1·687	1·620	1·558	1·500	1·447	1·397	1·351
11°	2·787	2·623	2·477	2·347	2·230	2·124	2·028	1·940	1·860	1·785	1·717	1·654	1·595	1·540	1·489
12	3·047	2·868	2·709	2·567	2·439	2·323	2·218	2·122	2·033	1·952	1·878	1·808	1·744	1·684	1·628
13	3·310	3·115	2·943	2·788	2·649	2·523	2·409	2·304	2·209	2·121	2·039	1·964	1·894	1·829	1·769
14	3·574	3·364	3·178	3·011	2·861	2·725	2·601	2·489	2·385	2·290	2·202	2·121	2·046	1·976	1·910
15	3·841	3·616	3·415	3·236	3·074	2·928	2·796	2·674	2·563	2·461	2·367	2·280	2·199	2·123	2·053
16°	4·111	3·869	3·655	3·463	3·290	3·134	2·992	2·862	2·743	2·634	2·533	2·440	2·353	2·272	2·197
17	4·383	4·125	3·897	3·692	3·508	3·341	3·190	3·052	2·925	2·808	2·701	2·601	2·509	2·423	2·342
18	4·658	4·384	4·141	3·924	3·728	3·551	3·390	3·243	3·108	2·985	2·870	2·764	2·666	2·575	2·489
19	4·936	4·646	4·389	4·158	3·951	3·763	3·593	3·437	3·294	3·163	3·042	2·930	2·825	2·728	2·638
20	5·218	4·911	4·639	4·395	4·176	3·978	3·797	3·633	3·482	3·343	3·215	3·097	2·987	2·884	2·788
21°	5·503	5·180	4·893	4·636	4·404	4·195	4·005	3·831	3·672	3·526	3·391	3·266	3·150	3·042	2·941
22	5·792	5·452	5·150	4·879	4·636	4·416	4·215	4·033	3·865	3·711	3·569	3·437	3·315	3·202	3·095
23	6·085	5·728	5·410	5·126	4·870	4·639	4·429	4·237	4·061	3·899	3·750	3·611	3·483	3·364	3·252
24	6·383	6·008	5·675	5·377	5·108	4·866	4·645	4·444	4·259	4·090	3·933	3·788	3·653	3·528	3·411
25	6·685	6·292	5·943	5·631	5·350	5·096	4·865	4·654	4·461	4·283	4·119	3·967	3·826	3·695	3·573
26°	6·992	6·581	6·216	5·890	5·596	5·330	5·089	4·868	4·666	4·480	4·308	4·150	4·002	3·865	3·737
27	7·304	6·875	6·494	6·153	5·846	5·568	5·316	5·086	4·875	4·680	4·501	4·335	4·181	4·037	3·904
28	7·622	7·175	6·777	6·421	6·101	5·811	5·548	5·307	5·087	4·884	4·697	4·524	4·363	4·213	4·074
29	7·946	7·480	7·065	6·694	6·360	6·058	5·783	5·533	5·303	5·092	4·897	4·716	4·548	4·392	4·247
	m. 44	m. 43	m. 42	m. 41	m. 40	m 39	m. 38	m. 37	m. 36	m. 35	m 34	m 33	m. 32	m. 31	m. 30

B.—II HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—O HOURS.

Stars.	m. 16	m. 17	m. 18	m. 19	m. 20	m. 21	m. 22	m. 23	m. 24	m. 25	m. 26	m. 27	m. 28	m. 29	m. 30
Fomalhaut	8·328	7·839	7·404	7·016	6·666	6·349	6·061	5·799	5·558	5·336	5·132	4·943	4·767	4·603	4·451
Castor . .	8·996	8·467	7·998	7·578	7·200	6·858	6·547	6·263	6·003	5·764	5·543	5·339	5·149	4·972	4·807
α Columbæ .	9·714	9·143	8·636	8·183	7·774	7·405	7·069	6·763	6·482	6·224	5·986	5·765	5·560	5·369	5·191
Vega. . .	11·48	10·81	10·21	9·670	9·188	8·752	8·355	7·993	7·661	7·356	7·074	6·813	6·571	6·345	6·135
α Phœnicis .	13·30	12·52	11·82	11·20	10·64	10·14	9·678	9·259	8·874	8·521	8·194	7·892	7·612	7·351	7·107
α Cygni . .	14·30	13·46	12·71	12·04	11·44	10·90	10·40	9·954	9·540	9·160	8·809	8·484	8·183	7·902	7·640
Capella . .	14·79	13·92	13·15	12·46	11·84	11·28	10·77	10·30	9·872	9·479	9·116	8·780	8·467	8·177	7·906
α Gruis . .	15·62	14·70	13·88	13·16	12·50	11·91	11·37	10·87	10·42	10·01	9·623	9·269	8·939	8·632	8·346
α Persei .	16·79	15·81	14·93	14·15	13·44	12·80	12·22	11·69	11·21	10·76	10·35	9·966	9·612	9·282	8·974
Benetnasch	16·97	15·97	15·09	14·29	13·58	12·94	12·35	11·81	11·32	10·87	10·46	10·07	9·713	9·380	9·069
Canopus .	18·78	17·67	16·69	15·82	15·03	14·31	13·66	13·07	12·53	12·03	11·57	11·14	10·75	10·38	10·03
α Cassiopeiæ	21·25	20·00	18·89	17·90	17·01	16·20	15·47	14·80	14·18	13·62	13·09	12·61	12·16	11·75	11·36
α Pavonis. .	22·12	20·82	19·67	18·64	17·71	16·87	16·10	15·40	14·76	14·18	13·63	13·13	12·66	12·23	11·82
Achernar .	22·72	21·39	20·20	19·14	18·18	17·32	16·54	15·82	15·16	14·56	14·00	13·48	13·00	12·56	12·14
ι Argûs . .	23·72	22·32	21·09	19·98	18·98	18·08	17·26	16·51	15·83	15·20	14·61	14·08	13·58	13·11	12·68
β Centauri .	24·72	23·27	21·98	20·82	19·78	18·84	17·99	17·21	16·50	15·84	15·23	14·67	14·15	13·66	13·21
Dubhe . .	27·29	25·69	24·26	22·99	21·84	20·81	19·86	19·00	18·21	17·49	16·82	16·20	15·62	15·08	14·58
α1 Crucis . .	27·59	25·97	24·53	23·24	22·08	21·03	20·08	19·21	18·41	17·68	17·00	16·37	15·79	15·25	14·74
α Tri. Austr	37·05	34·87	32·94	31·21	29·65	28·24	26·96	25·79	24·72	23·74	22·83	21·99	21·21	20·48	19·80
β Urs. Min. .	51·90	48·85	46·14	43·72	41·54	39·56	37·77	36·13	34·63	33·25	31·98	30·80	29·71	28·69	27·74
	m. 44	m. 43	m. 42	m. 41	m. 40	m. 39	m. 38	m. 37	m. 36	m. 35	m. 34	m. 33	m. 32	m. 31	m. 30

B.—II HOURS.

A.—0 HOURS.

Lat.	m. 32	m. 34	m. 36	m. 38	m. 40	m. 42	m. 44	m. 46	m. 48	m. 50	m. 52	m. 54	m. 56	m. 58	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·124	·117	·110	·104	·099	·094	·090	·086	·082	·079	·076	·073	·070	·067	·065
2	·248	·234	·220	·209	·198	·188	·180	·172	·164	·158	·151	·145	·140	·135	·130
3	·373	·351	·331	·313	·297	·283	·270	·258	·247	·236	·227	·218	·210	·203	·196
4	·498	·468	·442	·418	·397	·377	·360	·344	·329	·315	·303	·291	·280	·270	·261
5	·623	·585	·552	·523	·496	·472	·450	·430	·412	·395	·379	·364	·351	·338	·327
6°	·748	·703	·664	·628	·596	·567	·541	·517	·494	·474	·455	·438	·422	·406	·392
7	·874	·822	·775	·734	·696	·662	·632	·604	·578	·554	·532	·511	·492	·475	·458
8	1·000	·940	·887	·840	·797	·758	·723	·691	·661	·634	·609	·585	·564	·543	·525
9	1·127	1·060	1·000	·946	·898	·855	·815	·778	·745	·714	·686	·660	·635	·612	·591
10	1·255	1·180	1·113	1·054	1·000	·951	·907	·867	·830	·795	·764	·734	·707	·682	·658
11°	1·383	1·301	1·227	1·162	1·102	1·049	1·000	·955	·914	·877	·842	·810	·780	·752	·725
12	1·512	1·422	1·342	1·270	1·205	1·147	1·094	1·045	1·000	·959	·921	·885	·853	·822	·793
13	1·643	1·545	1·458	1·380	1·309	1·246	1·188	1·135	1·086	1·041	1·000	·962	·926	·893	·862
14	1·774	1·668	1·574	1·490	1·414	1·345	1·283	1·225	1·173	1·125	1·080	1·039	1·000	·964	·931
15	1·907	1·793	1·692	1·601	1·520	1·446	1·378	1·317	1·261	1·209	1·161	1·116	1·075	1·036	1·000
16°	2·040	1·919	1·810	1·714	1·626	1·547	1·475	1·409	1·349	1·293	1·242	1·194	1·150	1·109	1·070
17	2·175	2·046	1·930	1·827	1·734	1·650	1·573	1·503	1·438	1·379	1·324	1·273	1·226	1·182	1·141
18	2·312	2·174	2·051	1·942	1·843	1·753	1·672	1·597	1·529	1·466	1·407	1·353	1·303	1·256	1·213
19	2·450	2·304	2·174	2·058	1·953	1·858	1·771	1·692	1·620	1·553	1·491	1·434	1·381	1·331	1·285
20	2·590	2.435	2·298	2·175	2·064	1·964	1·872	1·789	1·712	1·642	1·577	1·516	1·460	1·407	1·358
21°	2·731	2·568	2·424	2·294	2·177	2·071	1·975	1·887	1·806	1·731	1·663	1·599	1·540	1·484	1·433
22	2·875	2·703	2·551	2·414	2·291	2·180	2·079	1·986	1·901	1·822	1·750	1·683	1 620	1·562	1·508
23	3·020	2·840	2·680	2·537	2·407	2·290	2·184	2·086	1·997	1·915	1·839	1·768	1·702	1·641	1·584
24	3·168	2·979	2·811	2·661	2·525	2·402	2·291	2·188	2·095	2·008	1·928	1·855	1·786	1·722	1·662
25	3·318	3·120	2·944	2·787	2·645	2·516	2·399	2·292	2·194	2·103	2·020	1·942	1·870	1·803	1·740
26°	3·470	3·263	3·079	2·915	2·766	2·632	2·509	2·397	2·295	2·200	2·113	2·032	1·956	1·886	1·820
27	3·625	3·409	3·217	3·045	2·890	2·749	2·621	2·504	2·397	2·298	2·207	2·122	2·044	1·970	1·902
28	3·783	3·558	3·357	3·177	3·015	2·869	2·735	2·613	2·501	2·398	2·303	2·215	2·133	2·056	1·984
29	3·944	3·709	3·500	3·312	3·144	2·991	2·852	2·725	2·608	2·500	2·401	2·309	2·223	2·143	2·069
30	4·108	3·863	3·645	3·450	3·274	3·115	2·970	2·838	2·716	2·604	2·501	2·405	2·316	2·232	2·155
31°	4·275	4·020	3·794	3·591	3·408	3·242	3·091	2·953	2·827	2·710	2·603	2·503	2·410	2·323	2·242
32	4·446	4·181	3·945	3·734	3·544	3·371	3·215	3·071	2·940	2·819	2·707	2·603	2·506	2·416	2·332
33	4·621	4·345	4·100	3·881	3·683	3·504	3·341	3·192	3·055	2·929	2·813	2·705	2·605	2·511	2·424
34	4·799	4·513	4·259	4·031	3·825	3·639	3·470	3·315	3·173	3·043	2·922	2·810	2·705	2·608	2·517
35	4·982	4·685	4·421	4·184	3·971	3·778	3·602	3·442	3·294	3·158	3·033	2·917	2·808	2·708	2·613
36°	5·170	4·861	4·587	4·342	4·120	3·920	3·738	3·571	3·418	3·277	3·147	3·026	2·914	2·809	2·711
37	5·362	5·042	4·758	4·503	4·274	4·066	3·877	3·704	3·545	3·399	3·264	3·139	3·022	2·914	2·812
38	5·559	5·228	4·933	4·669	4·431	4·215	4·019	3·840	3·676	3·524	3·384	3·254	3·134	3·021	2·916
39	5·762	5·418	5·113	4·839	4·593	4·369	4·166	3·980	3·810	3·653	3·508	3·373	3·248	3·131	3·022
40	5·971	5·615	5·298	5·014	4·759	4·527	4·317	4·124	3·948	3·785	3·635	3·495	3·365	3·245	3·132
41°	6·185	5·817	5·488	5·195	4·930	4·690	4·472	4·273	4·090	3·921	3·765	3·621	3·487	3·361	3·244
42	6·407	6·025	5·685	5·381	5·106	4·858	4·632	4·426	4·236	4·061	3·900	3·750	3·611	3·482	3·360
43	6·635	6·240	5·888	5·572	5·289	5·031	4·797	4·583	4·387	4·206	4·039	3·884	3·740	3·606	3·480
44	6·871	6·462	6·097	5·771	5·477	5·210	4·968	4·747	4·543	4·356	4·183	4·022	3·873	3·734	3·604
45	7·115	6·691	6·314	5·976	5·671	5·396	5·145	4·915	4·705	4·511	4·331	4·165	4·011	3·867	3·732
46°	7·368	6·929	6·538	6·188	5·873	5·587	5·327	5·090	4·872	4·671	4·485	4·313	4·153	4·004	3·865
47	7·630	7·175	6·771	6·408	6·082	5·786	5·517	5·271	5·045	4·837	4·645	4·467	4·301	4·147	4·002
48	7·902	7·431	7·012	6·637	6·299	5·992	5·714	5·459	5·225	5·010	4·811	4·626	4·454	4·294	4·145
49	8·185	7·697	7·263	6·874	6·524	6·207	5·918	5·654	5·412	5·189	4·983	4·792	4·614	4·448	4·293
50	8·480	7·974	7·524	7·122	6·759	6·430	6·131	5·858	5·607	5·376	5·162	4·964	4·780	4·608	4·448
51°	8·787	8·263	7·797	7·379	7·003	6·663	6·353	6·070	5·810	5·570	5·349	5·144	4·953	4·775	4·609
52	9·107	8·564	8·081	7·649	7·259	6·906	6·585	6·291	6·022	5·773	5·544	5·331	5·134	4·949	4·777
53	9·442	8·879	8·379	7·930	7·526	7·160	6·827	6·523	6·243	5·986	5·748	5·528	5·322	5·131	4·953
54	9·793	9·210	8·690	8·225	7·806	7·426	7·081	6·765	6·475	6·208	5·962	5·733	5·520	5·322	5·137
55	10·16	9·556	9·017	8·534	8·099	7·706	7·347	7·020	6·719	6·442	6·186	5·949	5·728	5·522	5·330
56°	10·55	9·920	9·361	8·859	8·408	7·999	7·627	7·287	6·975	6·687	6·422	6·175	5·946	5·733	5·533
57	10·96	10·30	9·722	9·202	8·733	8·308	7·922	7·569	7·244	6·946	6·670	6·414	6·176	5·954	5·747
58	11·39	10·71	10·10	9·563	9·076	8·635	8·233	7·866	7·529	7·219	6·932	6·666	6·419	6·188	5·973
59	11·84	11·14	10·51	9·945	9·439	8·980	8·562	8·180	7·830	7·507	7·209	6·932	6·675	6·435	6·211
60	12·32	11·59	10·94	10·35	9·823	9·345	8·911	8·513	8·149	7·813	7·502	7·215	6·947	6·697	6·464
	m. 28	m. 26	m. 24	m. 22	m. 20	m. 18	m. 16	m. 14	m. 12	m. 10	m. 8	m. 6	m. 4	m. 2	m. 0

A.—11 HOURS.

B.—0 HOURS.

Dec.	m. 32	m. 34	m. 36	m. 38	m. 40	m. 42	m. 44	m. 46	m. 48	m. 50	m. 52	m. 54	m. 56	m. 58	m. 60
0°	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
1	.125	.118	.112	.106	.101	.096	.091	.088	.084	.081	.078	.075	.072	.070	.067
2	.251	.236	.223	.212	.201	.192	.183	.175	.168	.161	.155	.150	.144	.140	.135
3	.377	.355	.335	.318	.302	.288	.275	.263	.252	.242	.233	.224	.217	.209	.202
4	.502	.473	.447	.424	.403	.384	.366	.351	.336	.323	.311	.300	.289	.279	.270
5	.629	.592	.559	.530	.504	.480	.459	.439	.421	.404	.389	.375	.362	.349	.338
6°	.755	.711	.672	.637	.605	.577	.551	.527	.506	.486	.467	.450	.434	.420	.406
7	.882	.831	.785	.744	.707	.674	.643	.616	.591	.567	.546	.526	.508	.490	.474
8	1.010	.951	.898	.852	.809	.771	.737	.705	.676	.649	.625	.602	.581	.561	.543
9	1.138	1.072	1.012	.900	.912	.869	.830	.794	.762	.732	.704	.678	.655	.633	.612
10	1.267	1.193	1.127	1.068	1.015	.968	.924	.884	.848	.815	.784	.755	.729	.704	.681
11°	1.397	1.315	1.243	1.178	1.119	1.067	1.019	.975	.935	.898	.864	.833	.803	.776	.751
12	1.527	1.438	1.359	1.288	1.224	1.166	1.114	1.066	1.022	.982	.945	.911	.879	.849	.821
13	1.659	1.562	1.476	1.399	1.330	1.267	1.210	1.158	1.110	1.067	1.026	.989	.954	.922	.892
14	1.791	1.687	1.594	1.511	1.436	1.368	1.307	1.251	1.199	1.152	1.108	1.068	1.031	.996	.963
15	1.925	1.813	1.713	1.623	1.543	1.470	1.404	1.344	1.289	1.238	1.191	1.148	1.108	1.070	1.035
16°	2.060	1.940	1.833	1.737	1.651	1.573	1.503	1.438	1.379	1.325	1.275	1.228	1.185	1.145	1.108
17	2.197	2.068	1.954	1.852	1.761	1.678	1.602	1.533	1.470	1.413	1.359	1.310	1.264	1.221	1.181
18	2.335	2.198	2.077	1.969	1.871	1.783	1.703	1.630	1.563	1.501	1.444	1.392	1.343	1.298	1.255
19	2.474	2.330	2.201	2.086	1.983	1.889	1.805	1.727	1.656	1.591	1.531	1.475	1.423	1.375	1.330
20	2.615	2.462	2.327	2.205	2.096	1.997	1.908	1.826	1.751	1.682	1.618	1.559	1.504	1.454	1.406
21°	2.758	2.597	2.454	2.326	2.211	2.106	2.012	1.925	1.846	1.774	1.706	1.644	1.587	1.533	1.483
22	2.903	2.733	2.583	2.448	2.327	2.217	2.117	2.027	1.943	1.867	1.796	1.731	1.670	1.614	1.561
23	3.050	2.872	2.713	2.572	2.444	2.329	2.225	2.129	2.042	1.961	1.887	1.818	1.755	1.695	1.640
24	3.199	3.012	2.846	2.698	2.504	2.443	2.333	2.233	2.141	2.057	1.979	1.907	1.840	1.778	1.720
25	3.351	3.155	2.981	2.825	2.685	2.559	2.444	2.339	2.243	2.154	2.073	1.998	1.928	1.862	1.802
26°	3.505	3.300	3.118	2.955	2.809	2.676	2.556	2.446	2.346	2.253	2.168	2.089	2.016	1.948	1.884
27	3.661	3.447	3.257	3.087	2.934	2.796	2.670	2.556	2.451	2.354	2.265	2.183	2.106	2.035	1.969
28	3.820	3.597	3.399	3.222	3.062	2.918	2.787	2.667	2.557	2.457	2.364	2.278	2.198	2.124	2.054
29	3.983	3.750	3.543	3.358	3.192	3.042	2.905	2.780	2.666	2.561	2.464	2.374	2.291	2.214	2.142
	m. 28	m. 26	m. 24	m. 22	m. 20	m. 18	m. 16	m. 14	m. 12	m. 10	m. 8	m. 6	m. 4	m. 2	m. 0

B.—11 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—0 HOURS.

Stars.	m. 32	m. 34	m. 36	m. 38	m. 40	m. 42	m. 44	m. 46	m. 48	m. 50	m. 52	m. 54	m. 56	m. 58	m. 60
Fomalhaut	4.174	3.930	3.714	3.520	3.346	3.188	3.045	2.914	2.794	2.684	2.582	2.489	2.401	2.320	2.245
Castor . .	4.509	4.245	4.011	3.802	3.614	3.443	3.289	3.147	3.018	2.899	2.790	2.688	2.594	2.506	2.424
α Columbæ .	4.869	4.584	4.331	4.105	3.902	3.718	3.551	3.399	3.259	3.131	3.012	2.903	2.801	2.706	2.618
Vega. . .	5.754	5.418	5.119	4.852	4.612	4.394	4.197	4.017	3.852	3.700	3.560	3.430	3.310	3.198	3.094
α Phœnicis .	6.665	6.276	5.930	5.620	5.342	5.090	4.862	4.653	4.462	4.286	4.124	3.974	3.834	3.705	3.584
α Cygni . .	7.165	6.747	6.375	6.042	5.743	5.472	5.226	5.002	4.796	4.607	4.433	4.272	4.122	3.983	3.853
Capella . .	7.415	6.981	6.597	6.252	5.943	5.663	5.408	5.176	4.963	4.768	4.587	4.420	4.266	4.121	3.987
α Gruis . .	7.828	7.370	6.964	6.601	6.274	5.978	5.709	5.464	5.240	5.033	4.843	4.667	4.503	4.351	4.209
α Persei .	8.417	7.925	7.488	7.097	6.746	6.428	6.139	5.875	5.634	5.412	5.207	5.018	4.842	4.678	4.526
Benetnasch	8.505	8.008	7.567	7.172	6.817	6.495	6.204	5.937	5.693	5.469	5.262	5.071	4.893	4.728	4.573
Canopus .	9.411	8.861	8.372	7.935	7.542	7.187	6.864	6.569	6.299	6.051	5.822	5.610	5.414	5.231	5.060
α Cassiopeiæ	10.65	10.03	9.476	8.981	8.536	8.134	7.769	7.435	7.130	6.849	6.590	6.350	6.127	5.920	5.727
α Pavonis. .	11.09	10.44	9.865	9.351	8.888	8.469	8.088	7.741	7.423	7.130	6.861	6.611	6.379	6.164	5.963
Achernar .	11.39	10.72	10.13	9.603	9.127	8.697	8.306	7.950	7.623	7.323	7.046	6.789	6.551	6.330	6.124
ι Argûs . .	11.89	11.19	10.58	10.02	9.528	9.079	8.671	8.298	7.957	7.644	7.355	7.087	6.839	6.608	6.392
β Centauri .	12.39	11.67	11.02	10.45	9.929	9.462	9.036	8.648	8.293	7.966	7.665	7.386	7.127	6.886	6.662
Dubhe . .	13.68	12.88	12.17	11.53	10.96	10.45	9.977	9.549	9.156	8.796	8.463	8.155	7.869	7.603	7.355
α¹ Crucis . .	13.83	13.02	12.30	11.66	11.08	10.56	10.09	9.652	9.256	8.891	8.555	8.243	7.955	7.686	7.435
α Tri. Austr. .	18.57	17.48	16.52	15.66	14.88	14.18	13.54	12.96	12.43	11.94	11.49	11.07	10.68	10.32	9.985
β Urs. Min. .	26.01	24.49	23.14	21.93	20.85	19.87	18.97	18.16	17.41	16.73	16.09	15.51	14.96	14.46	13.99
	m. 28	m. 26	m. 24	m. 22	m. 20	m. 18	m. 16	m. 14	m. 12	m. 10	m. 8	m. 6	m. 4	m. 2	m. 0

B.—11 HOURS.

A.—1 HOUR.

Lat.	m. 2	m. 4	m. 6	m. 8	m. 10	m. 12	m. 14	m. 16	m. 18	m. 20	m. 22	m. 24	m 26	m. 28	m. 30
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·063	·061	·059	·057	·055	·054	·052	·051	·049	·048	·047	·046	·044	·043	·042
2	·126	·122	·118	·114	·111	·108	·104	·101	·099	·096	·093	·091	·089	·086	·084
3	·189	·183	·177	·171	·166	·161	·157	·152	·148	·144	·140	·137	·133	·130	·127
4	·252	·244	·236	·229	·222	·215	·209	·203	·198	·192	·187	·182	·178	·173	·169
5	·315	·305	·295	·286	·277	·269	·262	·254	·247	·240	·234	·228	·222	·217	·211
6°	·379	·367	·355	·344	·333	·323	·314	·305	·297	·289	·281	·274	·267	·260	·254
7	·443	·428	·415	·402	·389	·378	·367	·357	·347	·337	·328	·320	·312	·304	·296
8	·507	·490	·474	·460	·446	·433	·420	·408	·397	·386	·376	·366	·357	·348	·339
9	·571	·552	·535	·518	·502	·487	·473	·460	·447	·435	·424	·413	·402	·392	·382
10	·636	·615	·595	.577	·559	·543	·527	·512	·498	·484	·472	·459	·448	·436	·426
11°	·701	·678	·656	·636	·616	·598	·581	·565	·549	·534	·520	·506	·493	·481	·469
12	·766	·741	·718	·695	·674	·654	·635	·617	·600	·584	·569	·554	·540	·526	·513
13	·832	·805	·779	·755	·732	·711	·690	·670	·652	·634	·618	·601	·586	·571	·557
14	·899	·870	·842	·816	·791	·767	·745	·724	·704	·685	·667	·650	·633	·617	·602
15	·966	·934	·905	·876	·850	·825	·801	·778	·757	·736	·717	·698	·680	·663	·647
16°	1·034	1·000	·968	·938	·909	·883	·857	·833	·810	·788	·767	·747	·728	·710	·692
17	1·102	1·066	1·032	1·000	·970	·941	·914	·888	·863	·840	·818	·796	·776	·757	·738
18	1·172	1·133	1·097	1·063	1·031	1·000	·971	·944	·918	·893	·869	·846	·825	·804	·784
19	1·242	1·201	1·162	1·126	1·092	1·060	1·029	1·000	·972	·946	·921	·897	·874	·852	·831
20	1·312	1·269	1·229	1·190	1·154	1·120	1·088	1·057	1·028	1·000	·973	·948	·924	·901	·879
21°	1·384	1·339	1·296	1·256	1·217	1·181	1·147	1.115	1·084	1·055	1·027	1·000	·974	·950	·927
22	1·457	1·409	1·364	1·322	1·281	1·243	1·208	1·173	1·141	1·110	1·081	1·053	1·026	1·000	·975
23	1·531	1·480	1·433	1·388	1·346	1·306	1·269	1·233	1·199	1·166	1·135	1·106	1·078	1·051	1·025
24	1·605	1·553	1·503	1·456	1·412	1·370	1·331	1·293	1·257	1·223	1·191	1·160	1·130	1·102	1·075
25	1·681	1·626	1·574	1·525	1·479	1·435	1·394	1·354	1·317	1·281	1·247	1·215	1·184	1·154	1·120
26°	1·759	1·701	1·647	1·595	1·547	1·501	1·458	1·416	1·377	1·340	1·305	1·271	1·238	1·207	1·177
27	1·837	1·777	1·720	1·667	1·616	1·568	1·523	1·480	1·439	1·400	1·363	1·327	1·294	1·261	1·230
28	1·917	1·854	1·795	1·739	1·686	1·636	1·589	1·544	1·502	1·461	1·422	1·385	1·350	1·316	1·284
29	1·999	1·933	1·871	1·813	1·758	1·705	1·657	1·610	1·565	1·523	1·483	1·444	1·407	1·372	1·338
30	2·082	2·013	1·949	1·888	1·831	1·777	1·726	1·677	1·630	1·586	1·544	1·504	1·466	1·429	1·394
31°	2·167	2·095	2·028	1·965	1·906	1·849	1·796	1·745	1·697	1·651	1·607	1·565	1·525	1·487	1·451
32	2·253	2·179	2·110	2·044	1·982	1·923	1·868	1·815	1·765	1·717	1·671	1·628	1·586	1·547	1·509
33	2·342	2·265	2·192	2·124	2·060	1·999	1·941	1·886	1·834	1·784	1·737	1·692	1·649	1·607	1·568
34	2·432	2·352	2·277	2·206	2·139	2·076	2·016	1·959	1·905	1·853	1·804	1·757	1·712	1·669	1·628
35	2·525	2·442	2·364	2·290	2·221	2·155	2·093	2·034	1·977	1·924	1·873	1·824	1·778	1·733	1·690
36°	2·620	2·534	2·453	2·376	2·304	2·236	2·171	2·110	2·052	1·996	1·943	1·893	1·844	1·798	1·754
37	2·717	2·628	2·544	2·465	2·390	2·319	2·252	2·188	2·128	2·070	2·015	1·963	1·913	1·865	1·819
38	2·817	2·725	2·638	2·555	2·478	2·405	2·335	2·269	2·206	2·147	2·090	2·036	1.984	1·934	1·887
39	2·920	2·824	2·734	2·649	2·568	2·492	2·420	2·352	2·287	2·225	2·166	2·110	2·056	2·004	1·955
40	3·026	2·926	2·833	2·745	2·661	2·582	2·508	2·437	2·370	2·305	2·244	2·186	2·130	2·077	2·026
41°	3·135	3·032	2·935	2·843	2·757	2·675	2·598	2·525	2·455	2·388	2·325	2·265	2·207	2·152	2·099
42	3·247	3·140	3·040	2·945	2·856	2·771	2·691	2·615	2·543	2·474	2·408	2·346	2·286	2·229	2·174
43	3·363	3·252	3·148	3·050	2·958	2·870	2·787	2·708	2·633	2·562	2·494	2·429	2·367	2·308	2·251
44	3·482	3·368	3·260	3·159	3·063	2·972	2·886	2·805	2·727	2·653	2·583	2·516	2·452	2·390	2·331
45	3·606	3·487	3·376	3·271	3·172	3·078	2·989	2·904	2·824	2·747	2·675	2·605	2·539	2·475	2·414
46°	3·734	3·611	3·496	3·387	3·284	3·187	3·095	3·007	2·924	2·845	2·770	2·698	2·629	2·563	2·500
47	3·867	3·740	3·620	3·508	3·401	3·300	3·205	3·114	3·028	2·946	2·868	2·794	2·722	2·654	2·589
48	4·005	3·873	3·749	3·633	3·522	3·418	3·319	3·225	3·136	3·051	2·970	2·893	2·819	2·749	2·681
49	4·148	4·012	3·884	3·763	3·649	3·540	3·438	3·341	3·249	3·161	3·077	2·997	2·920	2·847	2·777
50	4·297	4·156	4·023	3·898	3·780	3·668	3·562	3·461	3·365	3·274	3·187	3·105	3·025	2·950	2·877
51°	4·453	4·307	4·169	4·039	3·917	3·801	3·691	3·586	3·487	3·393	3·303	3·217	3·135	3·056	2·981
52	4·615	4·464	4·321	4·187	4·059	3·939	3·825	3·717	3·614	3·517	3·423	3·334	3·249	3·168	3·090
53	4·785	4·628	4·480	4·341	4·209	4·084	3·966	3·854	3·747	3·640	3·549	3·457	3·369	3·285	3·204
54	4·963	4·800	4·647	4·502	4·365	4·236	4·114	3·997	3·887	3·782	3·681	3·586	3·494	3·407	3·323
55	5·150	4·981	4·821	4·671	4·530	4·395	4·268	4·148	4·033	3·924	3·820	3·720	3·626	3·535	3·448
56°	5·346	5·170	5·005	4·849	4·702	4·563	4·431	4·306	4·187	4·073	3·965	3·862	3·764	3·669	3·579
57	5·553	5·370	5·198	5·037	4·884	4·739	4·602	4·472	4·348	4·231	4·119	4·011	3·909	3·811	3·718
58	5.771	5·581	5·403	5·234	5·076	4·925	4·783	4·648	4·519	4·397	4·280	4·169	4·063	3·961	3·864
59	6·001	5·804	5·619	5·444	5·278	5·122	4·974	4·833	4·700	4·573	4·451	4·336	4·225	4·119	4·018
60	6·246	6·040	5·847	5·665	5·493	5·331	5·177	5·030	4·891	4·759	4·633	4·512	4·397	4.287	4·182
	m. 58	m. 56	m. 54	m. 52	m. 50	m. 48	m 46	m 44	m. 42	m. 40	m. 38	m. 36	m. 34	m. 32	m. 30

A.—10 HOURS.

B.—I HOUR.

Dec.	m. 2	m. 4	m. 6	m. 8	m. 10	m. 12	m. 14	m. 16	m. 18	m. 20	m. 22	m. 24	m. 26	m. 28	m. 30
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·065	·063	·061	·060	·058	·057	·055	·054	·052	·051	·050	·049	·048	·047	·046
2	·131	·127	·123	·119	·116	·113	·110	·107	·105	·102	·100	·097	·095	·093	·091
3	·196	·190	·185	·179	·174	·170	·165	·161	·157	·153	·150	·146	·143	·140	·137
4	·262	·254	·246	·239	·233	·226	·220	·215	·209	·204	·200	·195	·191	·187	·183
5	·327	·317	·308	·299	·291	·283	·276	·269	·262	·256	·250	·244	·239	·234	·229
6°	·393	·381	·370	·359	·350	·340	·331	·323	·315	·307	·300	·293	·287	·281	·275
7	·459	·445	·432	·420	·408	·397	·387	·377	·368	·359	·351	·343	·335	·328	·321
8	·526	·510	·495	·481	·467	·455	·443	·432	·421	·411	·401	·392	·383	·375	·367
9	·593	·575	·558	·542	·527	·513	·499	·486	·474	·463	·452	·442	·432	·423	·414
10	·660	·640	·621	·603	·586	·571	·556	·542	·528	·516	·504	·492	·481	·471	·461
11°	·727	·705	·684	·665	·646	·629	·613	·597	·582	·568	·555	·542	·530	·519	·508
12	·795	·771	·748	·727	·707	·688	·670	·653	·637	·621	·607	·593	·580	·567	·555
13	·864	·838	·813	·790	·768	·747	·728	·709	·692	·675	·659	·644	·630	·616	·603
14	·933	·905	·878	·853	·829	·807	·786	·766	·747	·729	·712	·696	·680	·666	·652
15	1·003	·972	·943	·916	·891	·867	·844	·823	·803	·783	·765	·748	·731	·715	·700
16°	1·073	1·040	1·010	·981	·954	·928	·904	·881	·859	·838	·819	·800	·782	·765	·749
17	1·144	1·109	1·076	1·046	1·017	·989	·964	·939	·916	·894	·873	·853	·834	·816	·799
18	1·216	1·179	1·144	1·111	1·081	1·051	1·024	·998	·973	·950	·928	·907	·887	·867	·849
19	1·288	1·249	1·212	1·178	1·145	1·114	1·085	1·058	1·032	1·007	·983	·961	·939	·919	·900
20	1·362	1·320	1·282	1·245	1·210	1·178	1·147	1·118	1·090	1·064	1·039	1·016	·993	·972	·951
21°	1·436	1·393	1·352	1·313	1·277	1·242	1·210	1·179	1·150	1·122	1·096	1·071	1·047	1·025	1·003
22	1·512	1·466	1·423	1·382	1·344	1·307	1·273	1·241	1·210	1·181	1·154	1·127	1·102	1·079	1·056
23	1·588	1·540	1·495	1·452	1·412	1·374	1·338	1·304	1·272	1·241	1·212	1·184	1·158	1·133	1·109
24	1·666	1·615	1·568	1·523	1·481	1·441	1·403	1·368	1·334	1·302	1·271	1·242	1·215	1·189	1·163
25	1·745	1·692	1·642	1·595	1·551	1·509	1·470	1·432	1·397	1·363	1·332	1·301	1·272	1·245	1·219
26°	1·825	1·769	1·717	1·668	1·622	1·578	1·537	1·498	1·461	1·426	1·393	1·361	1·331	1·302	1·275
27	1·907	1·849	1·794	1·743	1·694	1·649	1·606	1·565	1·526	1·490	1·455	1·422	1·390	1·360	1·331
28	1·990	1·929	1·872	1·819	1·768	1·721	1·676	1·633	1·593	1·555	1·518	1·484	1·451	1·419	1·389
29	2·074	2·011	1·952	1·896	1·843	1·794	1·747	1·703	1·661	1·621	1·583	1·547	1·512	1·480	1·448
	m. 58	m. 56	m. 54	m. 52	m. 50	m. 48	m. 46	m. 44	m. 42	m. 40	m. 38	m. 36	m. 34	m. 32	m. 30

B.—10 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—I HOUR.

Stars.	m. 2	m. 4	m. 6	m. 8	m. 10	m. 12	m. 14	m. 16	m. 18	m. 20	m. 22	m. 24	m. 26	m. 28	m. 30
Fomalhaut	2·174	2·108	2·045	1·987	1·932	1·880	1·831	1·784	1·740	1·699	1·659	1·621	1·585	1·551	1·518
Castor . .	2·348	2·277	2·209	2·146	2·087	2·031	1·978	1·927	1·880	1·835	1·792	1·751	1·712	1·675	1·640
α Columbæ .	2·535	2·458	2·386	2·318	2·253	2·193	2·135	2·081	2·030	1·981	1·935	1·891	1·849	1·809	1·771
Vega. . .	2·997	2·905	2·820	2·739	2·663	2·591	2·524	2·460	2·399	2·341	2·287	2·235	2·185	2·138	2·093
α Phœnicis .	3·471	3·365	3·266	3·173	3·085	3·002	2·923	2·849	2·779	2·712	2·649	2·588	2·531	2·476	2·424
α Cygni . .	3·732	3·618	3·511	3·411	3·316	3·227	3·143	3·063	2·987	2·916	2·848	2·783	2·721	2·662	2·606
Capella . .	3·861	3·744	3·633	3·529	3·432	3·339	3·252	3·170	3·091	3·017	2·947	2·879	2·816	2·755	2·697
α Gruis . .	4·077	3·952	3·836	3·726	3·623	3·525	3·433	3·346	3·264	3·185	3·111	3·040	2·972	2·908	2·847
α Persei .	4·383	4·250	4·124	4·006	3·895	3·791	3·692	3·598	3·509	3·425	3·345	3·269	3·196	3·127	3·061
Benetnasch	4·429	4·294	4·168	4·049	3·936	3·830	3·730	3·636	3·546	3·461	3·380	3·303	3·230	3·160	3·093
Canopus .	4·901	4·752	4·611	4·480	4·355	4·238	4·128	4·023	3·924	3·829	3·740	3·655	3·574	3·496	3·422
α Cassiopeiæ	5·547	5·378	5·219	5·070	4·929	4·797	4·672	4·553	4·441	4·334	4·233	4·136	4·045	3·957	3·874
α Pavonis. .	5·775	5·599	5·434	5·279	5·132	4·994	4·864	4·740	4·623	4·512	4·407	4·306	4·211	4·120	4·033
Achernar .	5·931	5·750	5·580	5·421	5·271	5·129	4·995	4·868	4·748	4·634	4·526	4·423	4·324	4·231	4·142
ι Argûs . .	6·191	6·002	5·825	5·659	5·502	5·354	5·214	5·082	4·956	4·837	4·724	4·617	4·514	4·417	4·323
β Centauri .	6·452	6·255	6·071	5·897	5·734	5·580	5·434	5·296	5·165	5·041	4·923	4·811	4·705	4·603	4·506
Dubhe . .	7·124	6·907	6·703	6·511	6·331	6·161	6·000	5·847	5·703	5·566	5·436	5·312	5·194	5·082	4·975
α¹ Crucis . .	7·201	6·982	6·776	6·582	6·400	6·227	6·065	5·911	5·765	5·627	5·495	5·370	5·251	5·137	5·029
α Tri. Austr. .	9·670	9·376	9·099	8·839	8·594	8·363	8·144	7·938	7·742	7·556	7·379	7·211	7·051	6·899	6·753
β Urs. Min. .	13·55	13·13	12·75	12·38	12·04	11·72	11·41	11·12	10·85	10·58	10·34	10·10	9·878	9·664	9·460
	m. 58	m. 56	m. 54	m. 52	m. 50	m. 48	m. 46	m. 44	m. 42	m. 40	m. 38	m. 36	m. 34	m. 32	m. 30

B.—10 HOURS.

A.—1 HOUR.

Lat.	m. 32	m. 34	m. 36	m. 38	m. 40	m. 42	m. 44	m. 46	m. 48	m. 50	m. 52	m. 54	m. 56	m. 58	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·041	·040	·039	·038	·037	·037	·036	·035	·034	·034	·033	·032	·031	·031	·030
2	·082	·080	·078	·077	·075	·073	·072	·070	·068	·067	·066	·064	·063	·062	·060
3	·123	·121	·118	·115	·112	·110	·107	·105	·103	·101	·099	·097	·095	·093	·091
4	·165	·161	·157	·153	·150	·147	·143	·140	·137	·134	·132	·129	·126	·124	·121
5	·206	·201	·197	·192	·188	·183	·179	·175	·172	·168	·165	·161	·158	·155	·152
6°	·248	·242	·236	·231	·225	·220	·215	·211	·206	·202	·198	·194	·190	·186	·182
7	·289	·282	·276	·269	·263	·257	·252	·246	·241	·236	·231	·226	·222	·217	·213
8	·331	·323	·316	·308	·301	·295	·288	·282	·276	·270	·264	·259	·254	·248	·243
9	·373	·364	·356	·348	·340	·332	·325	·318	·311	·304	·298	·292	·286	·280	·274
10	·415	·406	·396	·387	·378	·370	·362	·354	·346	·339	·332	·325	·318	·312	·305
11°	·458	·447	.437	·427	·417	·408	·399	·390	·381	·373	·366	·358	·351	·344	·337
12	·501	·489	·477	·466	·456	·446	·436	·426	·417	·408	·400	·391	·383	·376	·368
13	·544	·531	·519	·507	·495	·484	·473	·463	·453	·443	·434	·425	·416	·408	·400
14	·587	·573	·560	·547	·535	·523	·511	·500	·489	·479	·469	·459	·450	·441	·432
15	·631	·616	·602	·588	·575	·562	·549	·537	·526	·515	·504	·494	·483	·474	·464
16°	·676	·659	·644	·629	·615	·601	·588	·575	·563	·551	·539	·528	·517	·507	·497
17	·720	·703	·687	·671	·656	·641	·627	·613	·600	·587	·575	·563	·552	·540	·530
18	·765	·747	·730	·713	·697	·681	·666	·652	·638	·624	·611	·598	·586	·574	·563
19	·811	·792	·773	·756	·738	·722	·706	·691	·676	·661	·648	·634	·621	·609	·596
20	·858	·837	·817	·799	·781	·763	·746	·730	·714	·699	·685	·670	·657	·643	·630
21°	·904	·883	·862	·842	·823	·805	·787	·770	·753	737	·722	·707	·693	·678	·665
22	·952	·929	·907	·887	·866	·847	·828	·810	·793	776	·760	·744	·729	·714	·700
23	1·000	·976	·953	·931	·910	·890	·870	·851	·833	·815	·798	·782	·766	·750	·735
24	1·049	1·024	1·000	·977	·955	·933	·913	·893	·874	·855	·837	·820	·803	·787	·771
25	1·099	1·072	1·047	1·023	1·000	·978	·956	·935	·915	·896	·877	·859	·841	·824	·808
26°	1·149	1·122	1·095	1·070	1·046	1·023	1·000	·978	·957	·937	·917	·898	·880	·862	·845
27	1·200	1·172	1·144	1·118	1·093	1·068	1·045	1·022	1·000	·979	·958	·938	·919	·901	·883
28	1·253	1·223	1·194	1·167	1·140	1·115	1·090	1·066	1·044	1·021	1·000	·979	·959	·940	·921
29	1·306	1·275	1·245	1·216	1·189	1·162	1·137	1·112	1·088	1·065	1·043	1·021	1·000	·980	·960
30	1·360	1·328	1·297	1·267	1·238	1·210	1·184	1·158	1·133	1·109	1·080	1·063	1·042	1·020	1·000
31°	1·416	1·382	1·350	1·318	1·289	1·260	1·232	1·205	1·179	1·154	1·130	1·107	1·084	1·062	1·041
32	1·472	1·437	1·403	1·371	1·340	1·310	1·281	1·253	1·226	1·200	1·175	1·151	1·127	1·104	1·082
33	1·530	1·494	1·459	1·425	1·393	1·362	1·331	1·303	1·275	1·248	1.221	1·196	1·172	1·148	1·125
34	1·589	1·551	1·515	1·480	1·446	1·414	1·383	1·353	1·324	1·296	1·269	1·242	1·217	1·192	1·168
35	1·650	1·610	1·573	1·536	1·502	1·468	1·436	1·404	1·374	1·345	1·317	1·290	1·263	1·238	1·213
36°	1·712	1·671	1·632	1·594	1·558	1·523	1·490	1·457	1·426	1·396	1·366	1·338	1·311	1·284	1·258
37	1·775	1·733	1·693	1·654	1·616	1·580	1·545	1·511	1·479	1·448	1·417	1·388	1·359	1·332	1·305
38	1·841	1·797	1·755	1·714	1·675	1·638	1·602	1·567	1·533	1·501	1·469	1·439	1·409	1·381	1·353
39	1·908	1·862	1·819	1·777	1·737	1·698	1·660	1·624	1·589	1·556	1·523	1·491	1·461	1·431	1·403
40	1·977	1·930	1·885	1·841	1·799	1·759	1·720	1·683	1·647	1·612	1·578	1·545	1·514	1·483	1·453
41°	2·048	1·999	1·952	1·907	1·864	1·822	1·782	1·744	1·706	1·670	1·635	1·601	1·568	1·536	1·506
42	2·121	2·071	2·022	1·976	1·931	1·888	1·846	1·806	1·767	1·730	1·693	1·658	1·624	1·591	1·560
43	2·197	2·145	2·094	2·046	2·000	1·955	1·912	1·870	1·830	1·791	1·754	1·717	1·682	1·648	1·615
44	2·275	2·221	2·169	2·119	2·071	2·025	1·980	1·937	1·895	1·855	1·816	1·779	1·742	1·707	1·673
45	2·356	2·300	2·246	2·194	2·145	2·097	2·050	2·006	1·963	1·921	1·881	1·842	1·804	1·767	1·732
46°	2·440	2·382	2·326	2·272	2·221	2·171	2·123	2·077	2·032	1·989	1·948	1·907	1·868	1·830	1·794
47	2·526	2·466	2·409	2·353	2·300	2·248	2·199	2·151	2·105	2·060	2·017	1·975	1·935	1·895	1·857
48	2·616	2·554	2·494	2·437	2·382	2·328	2·277	2·228	2·180	2·133	2·089	2·045	2·004	1·963	1·924
49	2·710	2·646	2·584	2·524	2·467	2·412	2·359	2·307	2·258	2·210	2·164	2·119	2·075	2·033	1·992
50	2·808	2·741	2·677	2·615	2·556	2·499	2·443	2·390	2·339	2·289	2·241	2·195	2·150	2·106	2·064
51°	2·909	2·840	2·774	2·710	2·648	2·589	2·532	2·477	2·424	2·372	2·323	2·274	2·228	2·183	2·139
52	3·015	2·944	2·875	2·809	2·745	2·683	2·624	2·567	2·512	2·459	2·407	2·357	2·309	2·262	2·217
53	3·126	3·052	2·981	2·912	2·846	2·782	2·721	2·662	2·604	2·549	2·496	2·444	2·394	2·346	2·299
54	3·243	3·165	3·091	3·020	2·952	2·886	2·822	2·761	2·701	2·644	2·589	2·535	2·483	2·433	2·384
55	3·365	3·285	3·208	3·134	3·063	2·994	2·928	2·864	2·803	2·743	2·686	2·630	2·576	2·524	2·474
56°	3·493	3·410	3·330	3·253	3·179	3·108	3·040	2·974	2·910	2·848	2·788	2·731	2·675	2·620	2·568
57	3·628	3·541	3·459	3·379	3·302	3·228	3·157	3·088	3·022	2·958	2·896	2·836	2·778	2·722	2·667
58	3·770	3·681	3·594	3·512	3·432	3·355	3·281	3·210	3·141	3·074	3·010	2·947	2·887	2·829	2·772
59	3·921	3·828	3·738	3·652	3·569	3·489	3·412	3·338	3·266	3·197	3·130	3·065	3·002	2·942	2·883
60	4.080	3·983	3·890	3·801	3·714	3·631	3·551	3·474	3·399	3·327	3·258	3·190	3·125	3·061	3·000
	m. 28	m. 26	m. 24	m. 22	m. 20	m. 18	m. 16	m. 14	m. 12	m. 10	m. 8	m. 6	m. 4	m. 2	m. 0

A.—10 HOURS.

B.—1 HOUR.

Dec.	m. 32	m. 34	m. 36	m. 38	m. 40	m. 42	m. 44	m. 46	m. 48	m. 50	m. 52	m. 54	m. 56	m. 58	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·045	·044	·043	·042	·041	·041	·040	·039	·038	·038	·037	·037	·036	·035	·035
2	·089	·088	·086	·084	·083	·081	·080	·078	·077	·076	·074	·073	·072	·071	·070
3	·134	·131	·129	·126	·124	·122	·120	·117	·115	·113	·112	·110	·108	·106	·105
4	·179	·175	·172	·169	·165	·162	·160	·157	·154	·151	·149	·147	·144	·142	·140
5	·224	·219	·215	·211	·207	·203	·200	·196	·193	·189	·186	·183	·180	·178	·175
6°	·269	·264	·258	·253	·249	·244	·240	·236	·232	·228	·224	·220	·217	·213	·210
7	·314	·308	·302	·296	·291	·285	·280	·275	·270	·266	·262	·257	·253	·249	·246
8	·360	·352	·346	·339	·333	·326	·321	·315	·310	·304	·299	·295	·290	·285	·281
9	·405	·397	·389	·382	·375	·368	·361	·355	·349	·343	·337	·332	·327	·322	·317
10	·451	·442	·434	·425	·417	·410	·402	·395	·388	·382	·376	·370	·364	·358	·353
11°	·497	·487	·478	·469	·460	·452	·443	·436	·428	·421	·414	·407	·401	·395	·389
12	·544	·533	·523	·513	·503	·494	·485	·476	·468	·460	·453	·445	·438	·432	·425
13	·591	·579	·568	·557	·546	·536	·527	·517	·509	·500	·492	·484	·476	·469	·462
14	·638	·625	·613	·601	·590	·579	·569	·559	·549	·540	·531	·523	·514	·506	·499
15	·686	·672	·659	·646	·634	·622	·611	·601	·590	·580	·571	·562	·553	·544	·536
16°	·734	·719	·705	·691	·678	·666	·654	·643	·632	·621	·611	·601	·591	·582	·573
17	·782	·767	·752	·737	·723	·710	·697	·685	·673	·662	·651	·641	·631	·621	·611
18	·832	·815	·799	·784	·769	·755	·741	·728	·716	·704	·692	·681	·670	·660	·650
19	·881	·864	·847	·830	·815	·800	·785	·772	·758	·746	·733	·722	·710	·699	·689
20	·932	·913	·895	·878	·861	·845	·830	·816	·802	·788	·775	·763	·751	·739	·728
21°	·982	·963	·944	·926	·908	·892	·876	·860	·846	·831	·818	·804	·792	·780	·768
22	1·034	1·013	·993	·974	·956	·938	·922	·905	·890	·875	·861	·847	·833	·820	·808
23	1·086	1·065	1·044	1·024	1·004	·986	·968	·951	·935	·919	·904	·890	·876	·862	·849
24	1·139	1·117	1·095	1·074	1·054	1·034	1·016	·998	·981	·964	·948	·933	·918	·904	·890
25	1·193	1·169	1·146	1·124	1·103	1·083	1·064	1·045	1·027	1·010	·993	·977	·962	·947	·933
26°	1·248	1·223	1·199	1·176	1·154	1·133	1·113	1·093	1·074	1·056	1·039	1·022	1·006	·990	·975
27	1·304	1·278	1·253	1·229	1·206	1·184	1·162	1·142	1·122	1·103	1·085	1·068	1·051	1·035	1·019
28	1·361	1·333	1·307	1·282	1·258	1·235	1·213	1·192	1·171	1·152	1·133	1·114	1·097	1·080	1·063
29	1·419	1·390	1·363	1·337	1·312	1·288	1·264	1·242	1·221	1·200	1·181	1·162	1·143	1·126	1·109
	m. 28	m. 26	m. 24	m. 22	m. 20	m. 18	m. 16	m. 14	m. 12	m. 10	m 8	m. 6	m. 4	m. 2	m. 0

B.—10 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—1 HOUR.

Stars.	m. 32	m. 34	m. 36	m. 38	m. 40	m. 42	m. 44	m. 46	m. 48	m. 50	m. 52	m. 54	m. 56	m. 58	m. 60
Fomalhaut	1·487	1·457	1·428	1·401	1·375	1·349	1·325	1·302	1·280	1·258	1·237	1·218	1·198	1·180	1·162
Castor . .	1·606	1·574	1·543	1·513	1·485	1·458	1·431	1·406	1·382	1·359	1·337	1·315	1·294	1·274	1·255
α Columbæ .	1·734	1·699	1·666	1·634	1·603	1·574	1·546	1·519	1·492	1·467	1·443	1·420	1·398	1·376	1·355
Vega. . .	2·049	2·008	1·969	1·931	1·895	1·860	1·827	1·795	1·764	1·734	1·706	1·678	1·652	1·626	1·602
α Phœnicis .	2·374	2·326	2·281	2·237	2·195	2·155	2·116	2·079	2·043	2·009	1·976	1·944	1·913	1·884	1·855
α Cygni . .	2·552	2·501	2·452	2·405	2·360	2·316	2·275	2·235	2·197	2·160	2·124	2·090	2·057	2·025	1·994
Capella . .	2·641	2·588	2·537	2·488	2·442	2·397	2·354	2·313	2·273	2·235	2·198	2·163	2·129	2·096	2·064
α Gruis . .	2·788	2·732	2·678	2·627	2·578	2·530	2·485	2·442	2·400	2·359	2·320	2·283	2·247	2·212	2·179
α Persei .	2·998	2·938	2·880	2·825	2·772	2·721	2·672	2·625	2·580	2·537	2·495	2·455	2·416	2·379	2·343
Benetnasch	3·029	2·969	2·910	2·854	2·801	2·749	2·700	2·653	2·607	2·563	2·521	2·481	2·442	2·404	2·367
Canopus .	3·352	3·285	3·220	3·158	3·099	3·042	2·988	2·935	2·885	2·836	2·790	2·745	2·702	2·660	2·619
α Cassiopeiæ	3·794	3·717	3·644	3·575	3·507	3·443	3·381	3·322	3·265	3·210	3·157	3·107	3·058	3·010	2·965
α Pavonis. .	3·950	3·870	3·794	3·722	3·652	3·585	3·521	3·459	3·399	3·342	3·287	3·234	3·183	3·134	3·087
Achernar .	4·056	3·975	3·897	3·822	3·750	3·681	3·615	3·552	3·491	3·432	3·376	3·322	3·269	3·219	3·170
ι Argûs . .	4·234	4·149	4·068	3·990	3·915	3·843	3·774	3·708	3·644	3·583	3·524	3·467	3·413	3·360	3·309
β Centauri .	4·413	4·324	4·239	4·158	4·080	4·005	3·933	3·864	3·798	3·734	3·673	3·614	3·556	3·502	3·448
Dubhe . .	4·872	4·774	4·680	4·591	4·505	4·422	4·343	4·267	4·193	4·123	4·055	3·990	3·927	3·866	3·807
α¹ Crucis .	4·925	4·826	4·731	4·641	4·554	4·470	4·390	4·313	4·239	4·168	4·099	4·033	3·969	3·908	3·849
α Tri. Austr. .	6·614	6·481	6·354	6·232	6·115	6·003	5·895	5·792	5·692	5·597	5·505	5·416	5·331	5·248	5·169
β Urs. Min. .	9·265	9·079	8·901	8·730	8·566	8·409	8·258	8·113	7·974	7·840	7·711	7·587	7·467	7·352	7·240
	m. 28	m. 26	m. 24	m. 22	m. 20	m. 18	m. 16	m. 14	m. 12	m. 10	m. 8	m. 6	m. 4	m. 2	m. 0

B.—10 HOURS.

A. — 2 HOURS.

Lat.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·029	·028	·027	·026	·025	·024	·023	·022	·022	·021	·020	·019	·019	·018	·017
2	·058	·056	·054	·052	·050	·048	·046	·045	·043	·042	·040	·039	·037	·036	·035
3	·087	·084	·081	·078	·075	·072	·070	·067	·065	·062	·060	·058	·056	·054	·052
4	·116	·112	·108	·104	·100	·096	·093	·090	·086	·083	·080	·078	·075	·072	·070
5	·146	·140	·135	·130	·125	·120	·116	·112	·108	·104	·101	·097	·094	·091	·087
6°	·175	·168	·162	·156	·150	·145	·139	·135	·130	·125	·121	·117	·113	·109	·105
7	·204	·196	·189	·182	·175	·169	·163	·157	·152	·146	·141	·136	·132	·127	·123
8	·234	·225	·216	·208	·201	·193	·187	·180	·174	·167	·162	·156	·151	·146	·141
9	·264	·253	·244	·235	·226	·218	·210	·203	·196	·189	·182	·176	·170	·164	·158
10	·294	·282	·272	·261	·252	·243	·234	·226	·218	·210	·203	·196	·189	·183	·176
11°	·324	·311	·299	·288	·278	·268	·258	·249	·240	·232	·224	·216	·208	·201	·194
12	·354	·340	·327	·315	·304	·293	·282	·272	·262	·253	·245	·236	·228	·220	·213
13	·384	·369	·356	·342	·330	·318	·306	·295	·285	·275	·266	·256	·248	·239	·231
14	·415	·399	·384	·370	·356	·343	·331	·319	·308	·297	·287	·277	·267	·258	·249
15	·446	·429	·413	·397	·383	·369	·356	·343	·331	·319	·308	·298	·287	·277	·268
16°	·477	·459	·442	·425	·410	·395	·381	·367	·354	·342	·330	·318	·307	·297	·287
17	·509	·489	·471	·453	·437	·421	·406	·391	·378	·364	·352	·340	·328	·317	·306
18	·541	·520	·500	·482	·464	·447	·431	·416	·401	·387	·374	·361	·348	·336	·325
19	·573	·551	·530	·510	·492	·474	·457	·441	·425	·410	·396	·382	·369	·357	·344
20	·606	·582	·560	·540	·520	·501	·483	·466	·449	·434	·419	·404	·390	·377	·364
21°	·639	·614	·591	·569	·548	·528	·509	·491	·474	·457	·442	·426	·412	·398	·384
22	·672	·647	·622	·599	·577	·556	·536	·517	·499	·481	·465	·449	·433	·418	·404
23	·706	·679	·654	·629	·606	·584	·563	·543	·524	·506	·488	·471	·455	·440	·424
24	·741	·713	·686	·660	·636	·613	·591	·570	·550	·531	·512	·494	·477	·461	·445
25	·776	·746	·718	·691	·666	·642	·619	·597	·576	·556	·536	·518	·500	·483	·466
26°	·812	·781	·751	·723	·697	·671	·647	·624	·602	·581	·561	·542	·523	·505	·488
27	·848	·815	·785	·755	·728	·701	·676	·652	·629	·607	·586	·566	·546	·528	·510
28	·885	·851	·819	·788	·759	·732	·706	·681	·657	·634	·612	·591	·570	·551	·532
29	·922	·887	·854	·822	·792	·763	·736	·709	·685	·661	·638	·616	·594	·574	·554
30	·961	·924	·889	·856	·825	·795	·766	·739	·713	·688	·664	·641	·619	·598	·577
31°	1·000	·962	·925	·891	·858	·827	·797	·769	·742	·716	·691	·667	·644	·622	·601
32	1·040	1·000	·962	·926	·892	·860	·829	·800	·772	·745	·719	·694	·670	·647	·625
33	1·081	1·039	1·000	·963	·927	·894	·862	·831	·802	·774	·747	·721	·696	·672	·649
34	1·123	1·079	1·039	1·000	·963	·928	·895	·863	·833	·804	·776	·749	·723	·698	·675
35	1·165	1·121	1·078	1·038	1·000	·964	·929	·896	·865	·834	·805	·778	·751	·725	·700
36°	1·209	1·163	1·119	1·077	1·038	1·000	·964	·930	·897	·866	·836	·807	·779	·752	·727
37	1·254	1·206	1·160	1·117	1·076	1·037	1·000	·965	·931	·898	·867	·837	·808	·780	·754
38	1·300	1·250	1·203	1·158	1·116	1·075	1·037	1·000	·965	·931	·899	·868	·838	·809	·781
39	1·348	1·296	1·247	1·201	1·156	1·115	1·075	1·036	1·000	·965	·932	·899	·868	·839	·810
40	1·396	1·343	1·292	1·244	1·198	1·155	1·114	1·074	1·036	1·000	·965	·932	·900	·869	·839
41°	1·447	1·391	1·339	1·289	1·241	1·196	1·154	1·113	1·073	1·036	1·000	·965	·932	·900	·869
42	1·499	1·441	1·387	1·335	1·286	1·239	1·195	1·152	1·112	1·073	1·036	1·000	·966	·932	·900
43	1·552	1·492	1·436	1·383	1·332	1·283	1·237	1·194	1·152	1·111	1·073	1·036	1·000	·966	·933
44	1·607	1·545	1·487	1·432	1·379	1·329	1·282	1·236	1·193	1·151	1·111	1·073	1·036	1·000	·966
45	1·664	1·600	1·540	1·483	1·428	1·376	1·327	1·280	1·235	1·192	1·150	1·111	1·072	1·036	1·000
46°	1·723	1·657	1·595	1·535	1·479	1·425	1·374	1·325	1·279	1·234	1·191	1·150	1·110	1·072	1·036
47	1·785	1·716	1·651	1·590	1·532	1·476	1·423	1·373	1·324	1·278	1·234	1·191	1·150	1·110	1·072
48	1·848	1·777	1·710	1·647	1·586	1·529	1·474	1·422	1·371	1·324	1·278	1·233	1·191	1·150	1·111
49	1·915	1·841	1·771	1·705	1·643	1·583	1·527	1·472	1·421	1·371	1·323	1·278	1·234	1·191	1·150
50	1·983	1·907	1·835	1·767	1·702	1·640	1·582	1·525	1·472	1·420	1·371	1·324	1·278	1·234	1·192
51°	2·055	1·976	1·902	1·831	1·764	1·700	1·639	1·581	1·525	1·472	1·421	1·371	1·324	1·279	1·235
52	2·130	2·048	1·971	1·898	1·828	1·762	1·699	1·638	1·581	1·525	1·472	1·422	1·373	1·325	1·280
53	2·209	2·124	2·043	1·967	1·895	1·827	1·761	1·699	1·639	1·582	1·527	1·474	1·423	1·374	1·327
54	2·291	2·203	2·119	2·041	1·966	1·894	1·827	1·762	1·700	1·640	1·583	1·529	1·476	1·425	1·379
55	2·377	2·286	2·199	2·117	2·040	1·966	1·895	1·828	1·764	1·702	1·643	1·586	1·532	1·479	1·428
56°	2·467	2·373	2·283	2·198	2·117	2·041	1·967	1·898	1·831	1·767	1·705	1·647	1·590	1·535	1·483
57	2·563	2·464	2·371	2·283	2·199	2·119	2·043	1·971	1·902	1·835	1·771	1·710	1·651	1·595	1·540
58	2·663	2·561	2·464	2·373	2·286	2·203	2·124	2·048	1·976	1·907	1·841	1·777	1·716	1·657	1·600
59	2·770	2·663	2·563	2·467	2·377	2·291	2·209	2·130	2·055	1·983	1·915	1·848	1·785	1·723	1·664
60	2·883	2·772	2·667	2·568	2·474	2·384	2·299	2·217	2·139	2·064	1·992	1·9[illegible]4	1·857	1·794	1·732
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 00

A. — 9 HOURS.

B.—2 HOURS.

Dec.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
0	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·034	·033	·032	·031	·030	·030	·029	·028	·028	·027	·027	·026	·026	·025	·025
2	·068	·066	·064	·062	·061	·059	·058	·057	·055	·054	·053	·052	·051	·050	·049
3	·102	·099	·096	·094	·091	·089	·087	·085	·083	·082	·080	·078	·077	·075	·074
4	·136	·132	·128	·125	·122	·119	·116	·114	·111	·109	·107	·105	·103	·101	·099
5	·170	·165	·161	·157	·153	·149	·145	·142	·139	·136	·133	·131	·128	·126	·124
6	·204	·198	·193	·188	·183	·179	·175	·171	·167	·164	·160	·157	·154	·151	·149
7	·238	·232	·225	·220	·214	·209	·204	·199	·195	·191	·187	·183	·180	·177	·174
8	·273	·265	·258	·251	·245	·239	·234	·228	·223	·219	·214	·210	·206	·202	·199
9	·308	·299	·291	·283	·276	·269	·263	·257	·252	·246	·241	·237	·232	·228	·224
10	·342	·333	·324	·315	·307	·300	·293	·286	·280	·274	·269	·264	·259	·254	·249
11	·377	·367	·357	·348	·339	·331	·323	·316	·309	·302	·296	·290	·285	·280	·275
12	·413	·401	·390	·380	·371	·362	·353	·345	·338	·331	·324	·318	·312	·306	·301
13	·448	·436	·424	·413	·403	·393	·384	·375	·367	·359	·352	·345	·339	·332	·326
14	·484	·471	·458	·446	·435	·424	·414	·405	·396	·388	·380	·373	·366	·359	·353
15	·520	·506	·492	·479	·407	·456	·445	·435	·426	·417	·408	·400	·393	·386	·379
16	·557	·541	·527	·513	·500	·488	·476	·466	·456	·446	·437	·429	·420	·413	·406
17	·594	·577	·561	·547	·533	·520	·508	·497	·486	·476	·466	·457	·448	·440	·432
18	·631	·613	·597	·581	·566	·553	·540	·528	·516	·505	·495	·486	·476	·468	·460
19	·669	·650	·632	·616	·600	·586	·572	·559	·547	·536	·525	·515	·505	·496	·487
20	·707	·687	·668	·651	·635	·619	·605	·591	·578	·566	·555	·544	·534	·524	·515
21	·745	·724	·705	·686	·669	·653	·638	·623	·610	·597	·585	·574	·563	·553	·543
22	·784	·762	·742	·723	·704	·687	·671	·656	·642	·629	·616	·604	·592	·582	·571
23	·824	·801	·779	·759	·740	·722	·705	·689	·674	·660	·647	·634	·622	·611	·600
24	·864	·840	·817	·796	·776	·757	·740	·723	·707	·693	·679	·665	·653	·641	·630
25	·905	·880	·856	·834	·813	·793	·775	·757	·741	·725	·711	·697	·684	·671	·659
26	·947	·920	·896	·872	·850	·830	·810	·792	·775	·759	·743	·729	·715	·702	·690
27	·989	·962	·936	·911	·888	·867	·847	·828	·810	·793	·777	·761	·747	·733	·721
28	1·032	1·003	·976	·951	·927	·905	·884	·864	·845	·827	·810	·795	·780	·765	·752
29	1·076	1·046	1·018	·991	·966	·943	·921	·900	·881	·862	·845	·828	·813	·798	·784
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 0

B.—9 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—2 HOURS.

Stars.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
Fomalhaut	1·128	1·096	1·067	1·039	1·013	·988	·965	·944	·923	·904	·886	·868	·852	·836	·822
Castor . .	1·218	1·184	1·152	1·122	1·094	1·068	1·043	1·019	·997	·976	·956	·938	·920	·903	·887
α Columbæ .	1·316	1·279	1·244	1·212	1·181	1·153	1·126	1·101	1·077	1·054	1·033	1·013	·994	·975	·958
Vega. .	1·555	1·511	1·470	1·432	1·396	1·362	1·331	1·301	1·272	1·246	1·221	1·197	1·174	1·153	1·132
α Phœnicis .	1·801	1·751	1·703	1·659	1·617	1·578	1·541	1·507	1·474	1·443	1·414	1·386	1·360	1·335	1·312
α Cygni . .	1·936	1·882	1·831	1·783	1·739	1·697	1·657	1·620	1·585	1·551	1·520	1·490	1·462	1·436	1·410
Capella . .	2·004	1·947	1·895	1·845	1·799	1·756	1·715	1·676	1·640	1·605	1·573	1·542	1·513	1·486	1·459
α Gruis . .	2·115	2·056	2·000	1·948	1·899	1·853	1·810	1·769	1·731	1·695	1·661	1·628	1·597	1·568	1·541
α Persei .	2·274	2·210	2·151	2·095	2·042	1·993	1·946	1·903	1·861	1·822	1·785	1·751	1·718	1·686	1·657
Benetnasch	2·298	2·234	2·173	2·117	2·064	2·014	1·967	1·923	1·881	1·841	1·804	1·769	1·736	1·704	1·674
Canopus .	2·543	2·472	2·405	2·342	2·283	2·228	2·176	2·127	2·081	2·038	1·996	1·957	1·920	1·885	1·852
α Cassiopeiæ	2·878	2·797	2·722	2·651	2·584	2·522	2·463	2·408	2·355	2·306	2·259	2·215	2·174	2·134	2·096
α Pavonis. .	2·996	2·912	2·834	2·760	2·691	2·626	2·564	2·507	2·452	2·401	2·352	2·306	2·263	2·222	2·183
Achernar .	3·077	2·991	2·910	2·834	2·763	2·696	2·634	2·574	2·518	2·466	2·416	2·369	2·324	2·282	2·241
ι Argûs . .	3·212	3·122	3·038	2·959	2·884	2·815	2·749	2·687	2·629	2·574	2·522	2·473	2·426	2·382	2·340
β Centauri .	3·348	3·254	3·166	3·083	3·006	2·933	2·865	2·801	2·740	2·682	2·628	2·577	2·528	2·482	2·438
Dubhe . .	3·696	3·592	3·495	3·404	3·319	3·239	3·163	3·092	3·025	2·962	2·902	2·845	2·791	2·740	2·692
α_1 Crucis .	3·736	3·631	3·533	3·441	3·355	3·274	3·198	3·126	3·058	2·994	2·933	2·876	2·822	2·770	2·722
α Tri. Austr .	5·018	4·877	4·745	4·621	4·506	4·397	4·294	4·198	4·106	4·020	3·939	3·862	3·789	3·720	3·655
β Urs. Min. .	7·029	6·832	6·647	6·474	6·312	6·159	6·015	5·880	5·753	5·632	5·518	5·410	5·308	5·211	5·120
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 0

B.—9 HOURS.

A.—3 HOURS.

Lat.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m 52	m. 56	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·017	·016	·016	·015	·015	·014	·014	·013	·013	·012	·012	·011	·011	·010	·010
2	·034	·033	·031	·030	·029	·028	·027	·026	·025	·025	·024	·023	·022	·021	·020
3	·051	·049	·047	·046	·044	·042	·041	·039	·038	·037	·035	·034	·033	·031	·030
4	·068	·065	·063	·061	·059	·057	·055	·053	·051	·049	·047	·045	·044	·042	·040
5	·084	·082	·079	·076	·073	·071	·068	·066	·064	·061	·059	·057	·055	·053	·051
6°	·101	·098	·095	·091	·088	·085	·082	·079	·076	·074	·071	·068	·066	·063	·061
7	·119	·114	·111	·107	·103	·099	·096	·093	·089	·086	·083	·080	·077	·074	·071
8	·136	·131	·127	·122	·118	·114	·110	·106	·102	·098	·095	·091	·088	·084	·081
9	·153	·148	·143	·138	·133	·128	·124	·119	·115	·111	·107	·103	·099	·095	·091
10	·170	·164	·159	·153	·148	·143	·138	·133	·128	·123	·119	·115	·110	·106	·102
11°	·188	·181	·175	·169	·163	·157	·152	·146	·141	·136	·131	·126	·121	·117	·112
12	·205	·198	·191	·185	·178	·172	·166	·160	·154	·149	·143	·138	·133	·128	·123
13	·223	·215	·208	·201	·194	·187	·180	·174	·168	·162	·156	·150	·144	·139	·133
14	·241	·233	·224	·217	·209	·202	·195	·188	·181	·175	·168	·162	·156	·150	·144
15	·259	·250	·241	·233	·225	·217	·209	·202	·195	·188	·181	·174	·167	·161	·155
16°	·277	·267	·258	·249	·241	·232	·224	·216	·208	·201	·193	·186	·179	·172	·166
17	·295	·285	·275	·266	·257	·248	·239	·230	·222	·214	·206	·199	·191	·184	·177
18	·314	·303	·293	·282	·273	·263	·254	·245	·236	·228	·219	·211	·203	·195	·188
19	·333	·321	·310	·299	·289	·279	·269	·259	·250	·241	·232	·224	·215	·207	·199
20	·351	·339	·328	·316	·305	·295	·284	·274	·264	·255	·246	·236	·227	·219	·210
21°	·371	·358	·346	·334	·322	·311	·300	·289	·279	·269	·259	·249	·240	·231	·222
22	·390	·377	·364	·351	·339	·327	·316	·304	·294	·283	·273	·262	·252	·243	·233
23	·410	·396	·382	·369	·356	·344	·332	·320	·308	·297	·286	·276	·265	·255	·245
24	·430	·415	·401	·387	·374	·361	·348	·336	·323	·312	·300	·289	·278	·268	·257
25	·450	·435	·420	·405	·391	·378	·364	·351	·339	·327	·315	·303	·291	·280	·269
26°	·471	·455	·439	·424	·409	·395	·381	·368	·354	·342	·329	·317	·305	·293	·282
27	·492	·475	·459	·443	·428	·413	·398	·384	·370	·357	·344	·331	·318	·306	·294
28	·513	·496	·479	·462	·446	·431	·415	·401	·386	·372	·359	·345	·332	·319	·307
29	·535	·517	·499	·482	·465	·449	·433	·418	·403	·388	·374	·360	·346	·333	·320
30	·558	·538	·520	·502	·484	·468	·451	·435	·419	·404	·389	·375	·361	·347	·333
31°	·580	·560	·541	·522	·504	·487	·469	·453	·437	·421	·405	·390	·375	·361	·347
32	·603	·583	·563	·543	·524	·506	·488	·471	·454	·438	·421	·406	·390	·375	·361
33	·627	·606	·585	·565	·545	·526	·507	·489	·472	·455	·438	·422	·406	·390	·375
34	·651	·629	·607	·586	·566	·546	·527	·508	·490	·472	·455	·438	·421	·405	·389
35	·676	·653	·630	·609	·588	·567	·547	·528	·509	·490	·472	·455	·438	·421	·404
36°	·702	·678	·654	·632	·610	·588	·568	·547	·528	·509	·490	·472	·454	·437	·419
37	·728	·703	·679	·655	·632	·610	·589	·568	·547	·528	·508	·489	·471	·453	·435
38	·754	·729	·703	·679	·656	·633	·610	·589	·568	·547	·527	·507	·488	·469	·451
39	·782	·755	·729	·704	·679	·656	·633	·610	·588	·567	·546	·526	·506	·487	·468
40	·810	·782	·756	·729	·704	·679	·656	·632	·610	·588	·566	·545	·524	·504	·484
41°	·839	·811	·783	·756	·729	·704	·679	·655	·632	·609	·586	·565	·543	·522	·502
42	·870	·840	·811	·783	·756	·729	·703	·679	·654	·630	·607	·585	·563	·541	·520
43	·901	·870	·840	·811	·782	·755	·729	·703	·678	·653	·629	·606	·583	·560	·538
44	·933	·901	·870	·839	·810	·782	·754	·728	·702	·676	·651	·627	·603	·580	·558
45	·966	·933	·900	·869	·839	·810	·781	·754	·727	·700	·675	·649	·625	·601	·577
46°	1·000	·966	·932	·900	·869	·839	·809	·780	·752	·725	·698	·672	·647	·622	·598
47	1·036	1·000	·966	·932	·900	·868	·838	·808	·779	·751	·723	·696	·670	·644	·619
48	1·073	1·036	1·000	·965	·932	·899	·868	·837	·807	·778	·749	·721	·694	·667	·641
49	1·111	1·073	1·036	1·000	·965	·932	·899	·867	·836	·805	·776	·747	·719	·691	·664
50	1·151	1·111	1·073	1·036	1·000	·965	·931	·898	·866	·834	·804	·774	·745	·716	·688
51°	1·193	1·152	1·112	1·073	1·036	1·000	·965	·931	·897	·865	·833	·802	·772	·742	·713
52	1·236	1·194	1·152	1·113	1·074	1·036	1·000	·965	·930	·896	·863	·831	·800	·769	·739
53	1·282	1·237	1·195	1·154	1·114	1·075	1·037	1·000	·964	·929	·895	·862	·829	·797	·766
54	1·329	1·283	1·239	1·196	1·155	1·115	1·075	1·037	1·000	·964	·928	·894	·860	·827	·795
55	1·379	1·332	1·286	1·241	1·198	1·156	1·116	1·076	1·038	1·000	·963	·927	·892	·858	·825
56°	1·432	1·383	1·335	1·289	1·244	1·201	1·158	1·117	1·077	1·038	1·000	·963	·926	·891	·856
57	1·487	1·436	1·387	1·339	1·292	1·247	1·203	1·160	1·119	1·078	1·039	1·000	·962	·925	·889
58	1·545	1·492	1·441	1·391	1·343	1·296	1·250	1·206	1·163	1·121	1·079	1·039	1·000	·962	·924
59	1·607	1·552	1·499	1·447	1·396	1·348	1·300	1·254	1·209	1·165	1·123	1·081	1·040	1·000	·961
60	1·673	1·615	1·560	1·506	1·453	1·403	1·353	1·305	1·258	1·213	1·168	1·125	1·082	1·041	1·000
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m 20	m. 16	m. 12	m. 8	m. 4	m. 00

A.—8 HOURS.

B.—3 HOURS.

Dec.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
0°	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
1	.024	.024	.023	.023	.023	.023	.022	.022	.022	.021	.021	.021	.021	.020	.020
2	.049	.048	.047	.046	.046	.045	.044	.044	.043	.043	.042	.042	.041	.041	.040
3	.073	.072	.071	.069	.068	.067	.067	.066	.065	.064	.063	.002	.062	.061	.061
4	.097	.096	.094	.093	.091	.090	.089	.088	.086	.085	.084	.083	.083	.082	.081
5	.122	.120	.118	.116	.114	.113	.111	.110	.108	.107	.106	.104	.103	.102	.101
6°	.146	.144	.141	.139	.137	.135	.133	.132	.130	.128	.127	.125	.124	.123	.121
7	.171	.168	.165	.163	.160	.158	.156	.154	.152	.150	.148	.146	.145	.143	.142
8	.195	.192	.189	.186	.183	.181	.178	.176	.174	.172	.170	.168	.166	.164	.162
9	.220	.217	.213	.210	.207	.204	.201	.198	.196	.193	.191	.189	.187	.185	.183
10	.245	.241	.237	.234	.230	.227	.224	.221	.218	.215	.213	.210	.208	.206	.204
11°	.270	.266	.262	.258	.254	.250	.247	.243	.240	.237	.234	.232	.229	.227	.224
12	.295	.291	.286	.282	.277	.274	.270	.266	.263	.259	.256	.253	.251	.248	.245
13	.321	.316	.311	.306	.301	.297	.293	.289	.285	.282	.278	.275	.272	.269	.267
14	.347	.341	.336	.330	.325	.321	.316	.312	.308	.304	.301	.297	.294	.291	.288
15	.372	.366	.361	.355	.350	.345	.340	.336	.331	.327	.323	.319	.316	.313	.309
16°	.399	.392	.386	.380	.374	.369	.364	.359	.354	.350	.346	.342	.338	.335	.331
17	.425	.418	.411	.405	.399	.393	.388	.383	.378	.373	.369	.365	.361	.357	.353
18	.452	.444	.437	.431	.424	.418	.412	.407	.402	.397	.392	.387	.383	.379	.375
19	.479	.471	.463	.456	.449	.443	.437	.431	.426	.420	.415	.411	.406	.402	.398
20	.506	.498	.490	.482	.475	.468	.462	.456	.450	.444	.439	.434	.429	.425	.420
21°	.534	.525	.517	.509	.501	.494	.487	.481	.474	.469	.463	.458	.453	.448	.443
22	.562	.552	.544	.535	.527	.520	.513	.506	.499	.493	.487	.482	.476	.471	.467
23	.590	.580	.571	.562	.554	.546	.539	.532	.525	.518	.512	.506	.501	.495	.490
24	.619	.609	.599	.590	.581	.573	.565	.557	.550	.544	.537	.531	.525	.519	.514
25	.648	.638	.627	.618	.609	.600	.592	.584	.576	.569	.562	.556	.550	.544	.538
26°	.678	.667	.656	.646	.637	.628	.619	.611	.603	.595	.588	.582	.575	.569	.563
27	.708	.697	.686	.675	.665	.656	.647	.638	.630	.622	.615	.608	.601	.594	.588
28	.739	.727	.715	.705	.694	.684	.675	.666	.657	.649	.641	.634	.627	.620	.614
29	.771	.758	.746	.734	.724	.713	.703	.694	.685	.677	.669	.661	.654	.647	.640
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 0

B.—8 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—3 HOURS.

Stars.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
Fomalhaut	.808	.794	.782	.770	.758	.748	.737	.727	.718	.709	.701	.693	.685	.678	.671
Castor	.872	.858	.844	.831	.819	.807	.796	.786	.776	.766	.757	.748	.740	.732	.725
α Columbæ	.942	.926	.912	.898	.885	.872	.860	.848	.838	.827	.817	.808	.799	.790	.782
Vega	1.113	1.095	1.078	1.061	1.045	1.030	1.016	1.003	.990	.978	.966	.955	.944	.934	.925
α Phœnicis	1.290	1.268	1.248	1.229	1.211	1.194	1.177	1.162	1.147	1.132	1.119	1.106	1.094	1.082	1.071
α Cygni	1.386	1.364	1.342	1.321	1.302	1.283	1.266	1.249	1.233	1.217	1.203	1.189	1.176	1.163	1.152
Capella	1.435	1.411	1.389	1.367	1.347	1.328	1.310	1.292	1.276	1.260	1.245	1.230	1.217	1.204	1.192
α Gruis	1.514	1.490	1.466	1.443	1.422	1.402	1.382	1.364	1.347	1.330	1.314	1.299	1.285	1.271	1.258
α Persei	1.628	1.602	1.576	1.552	1.529	1.507	1.486	1.467	1.448	1.430	1.413	1.397	1.381	1.367	1.353
Benetnasch	1.646	1.618	1.593	1.568	1.545	1.523	1.502	1.482	1.463	1.445	1.428	1.411	1.396	1.381	1.367
Canopus	1.821	1.791	1.762	1.735	1.710	1.685	1.662	1.640	1.619	1.599	1.580	1.562	1.544	1.528	1.512
α Cassiopeiæ	2.061	2.027	1.995	1.964	1.935	1.907	1.881	1.856	1.832	1.810	1.788	1.767	1.748	1.729	1.712
α Pavonis	2.145	2.110	2.077	2.045	2.015	1.986	1.958	1.932	1.908	1.884	1.862	1.840	1.820	1.800	1.782
Achernar	2.203	2.167	2.133	2.100	2.069	2.039	2.011	1.985	1.959	1.935	1.912	1.890	1.869	1.849	1.830
ι Argûs	2.300	2.262	2.226	2.192	2.160	2.129	2.100	2.072	2.045	2.020	1.996	1.973	1.951	1.930	1.910
β Centauri	2.397	2.358	2.320	2.285	2.251	2.219	2.188	2.159	2.131	2.105	2.080	2.056	2.033	2.012	1.991
Dubhe	2.646	2.603	2.562	2.522	2.485	2.450	2.416	2.384	2.353	2.324	2.296	2.270	2.245	2.221	2.198
α Crucis	2.675	2.631	2.590	2.550	2.512	2.476	2.442	2.410	2.379	2.349	2.321	2.295	2.269	2.245	2.222
α Tri. Austr.	3.593	3.534	3.477	3.424	3.374	3.325	3.280	3.236	3.194	3.155	3.117	3.081	3.047	3.015	2.984
β Urs. Min.	5.033	4.950	4.871	4.797	4.726	4.658	4.594	4.533	4.475	4.419	4.367	4.317	4.269	4.223	4.180
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 0

B.—8 HOURS.

A.—4 HOURS.

Lat.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·010	·009	·009	·009	·008	·008	·007	·007	·007	·006	·006	·006	·005	·005	·005
2	·019	·019	·018	·017	·016	·016	·015	·014	·013	·013	·012	·011	·011	·010	·009
3	·029	·028	·027	·026	·024	·023	·022	·021	·020	·019	·018	·017	·016	·015	·014
4	·039	·037	·036	·034	·033	·031	·030	·028	·027	·026	·024	·023	·021	·020	·019
5	·048	·047	·045	·043	·041	·039	·037	·035	·034	·032	·030	·028	·027	·025	·023
6°	·058	·056	·054	·051	·049	·047	·045	·043	·040	·038	·036	·034	·032	·030	·028
7	·068	·065	·063	·060	·057	·055	·052	·050	·047	·045	·042	·040	·038	·035	·033
8	·078	·075	·072	·069	·066	·063	·060	·057	·054	·051	·048	·046	·043	·040	·038
9	·088	·084	·081	·077	·074	·071	·067	·064	·061	·058	·055	·051	·048	·045	·042
10	·098	·094	·090	·086	·082	·079	·075	·071	·068	·064	·061	·057	·054	·051	·047
11°	·108	·103	·099	·095	·091	·087	·083	·079	·075	·071	·067	·063	·059	·056	·052
12	·118	·113	·108	·104	·099	·095	·090	·086	·082	·077	·073	·069	·065	·061	·057
13	·128	·123	·118	·113	·108	·103	·098	·093	·089	·084	·079	·075	·071	·066	·062
14	·138	·133	·127	·122	·116	·111	·106	·101	·096	·091	·086	·081	·076	·071	·067
15	·149	·142	·137	·131	·125	·119	·114	·108	·103	·098	·092	·087	·082	·077	·072
16°	·159	·152	·146	·140	·134	·128	·122	·116	·110	·104	·099	·093	·088	·082	·077
17	·169	·163	·156	·149	·143	·136	·130	·124	·117	·111	·105	·099	·093	·088	·082
18	·180	·173	·166	·158	·152	·145	·138	·131	·125	·118	·112	·106	·099	·093	·087
19	·191	·183	·175	·168	·161	·153	·146	·139	·132	·125	·119	·112	·105	·099	·092
20	·202	·194	·185	·178	·170	·162	·154	·147	·140	·132	·125	·118	·111	·104	·098
21°	·213	·204	·196	·187	·179	·171	·163	·155	·147	·140	·132	·125	·117	·110	·103
22	·224	·215	·206	·197	·188	·180	·171	·163	·155	·147	·139	·131	·124	·116	·108
23	·235	·226	·216	·207	·198	·189	·180	·171	·163	·154	·146	·138	·130	·122	·114
24	·247	·237	·227	·217	·208	·198	·189	·180	·171	·162	·153	·145	·136	·128	·119
25	·258	·248	·238	·227	·217	·208	·198	·188	·179	·170	·161	·152	·143	·134	·125
26°	·270	·259	·249	·238	·227	·217	·207	·197	·187	·178	·168	·158	·149	·140	·131
27	·282	·271	·260	·249	·238	·227	·216	·206	·196	·185	·175	·166	·156	·146	·137
28	·295	·283	·271	·259	·248	·237	·226	·215	·204	·194	·183	·173	·163	·152	·142
29	·307	·295	·282	·270	·258	·247	·235	·224	·213	·202	·191	·180	·169	·159	·149
30	·320	·307	·294	·282	·269	·257	·245	·233	·222	·210	·199	·188	·177	·166	·155
31°	·333	·319	·306	·293	·280	·268	·255	·243	·231	·219	·207	·195	·184	·172	·161
32	·346	·332	·318	·305	·291	·278	·265	·252	·240	·227	·215	·203	·191	·179	·167
33	·360	·345	·331	·317	·303	·289	·276	·262	·249	·236	·224	·211	·199	·186	·174
34	·374	·359	·344	·329	·315	·300	·286	·273	·259	·246	·232	·219	·206	·193	·181
35	·388	·372	·357	·342	·327	·312	·297	·283	·269	·255	·241	·228	·214	·201	·188
36°	·403	·386	·370	·354	·339	·323	·308	·294	·279	·264	·250	·236	·222	·208	·195
37	·418	·401	·384	·368	·351	·336	·320	·304	·289	·274	·259	·245	·230	·216	·202
38	·433	·415	·398	·381	·364	·348	·332	·316	·300	·284	·269	·254	·239	·224	·209
39	·449	·431	·413	·395	·378	·361	·344	·327	·311	·295	·279	·263	·248	·232	·217
40	·465	·446	·428	·409	·391	·374	·356	·339	·322	·305	·289	·273	·257	·241	·225
41°	·482	·462	·443	·424	·405	·387	·369	·351	·334	·316	·299	·282	·266	·249	·233
42	·499	·479	·459	·439	·420	·401	·382	·364	·346	·328	·310	·293	·275	·258	·241
43	·517	·496	·475	·455	·435	·415	·396	·377	·358	·339	·321	·303	·285	·267	·250
44	·535	·513	·492	·471	·450	·430	·410	·390	·371	·351	·333	·314	·295	·277	·259
45	·554	·532	·510	·488	·466	·445	·424	·404	·384	·364	·344	·325	·306	·287	·268
46°	·574	·551	·528	·505	·483	·461	·440	·418	·398	·377	·357	·336	·317	·297	·277
47	·594	·570	·546	·523	·500	·477	·455	·433	·412	·390	·369	·348	·328	·307	·287
48	·616	·591	·566	·542	·518	·494	·471	·449	·426	·404	·382	·361	·340	·318	·298
49	·638	·612	·586	·561	·536	·512	·488	·465	·442	·419	·396	·374	·352	·330	·308
50	·661	·634	·607	·581	·556	·531	·506	·481	·457	·434	·410	·387	·364	·342	·319
51°	·685	·657	·629	·602	·576	·550	·524	·499	·474	·449	·425	·401	·378	·354	·331
52	·709	·681	·652	·624	·597	·570	·543	·517	·491	·466	·441	·416	·391	·367	·343
53	·736	·706	·676	·647	·619	·591	·563	·536	·509	·483	·457	·431	·406	·381	·356
54	·763	·732	·701	·671	·642	·613	·584	·556	·528	·501	·474	·447	·421	·395	·369
55	·792	·759	·728	·697	·666	·636	·606	·577	·548	·520	·492	·464	·437	·410	·383
56°	·822	·788	·755	·723	·691	·660	·629	·599	·569	·540	·510	·482	·453	·425	·397
57	·854	·819	·785	·751	·718	·686	·654	·622	·591	·560	·530	·500	·471	·442	·413
58	·887	·851	·815	·781	·746	·713	·679	·647	·614	·582	·551	·520	·489	·459	·429
59	·923	·885	·848	·812	·776	·741	·706	·672	·639	·606	·573	·541	·509	·477	·446
60	·960	·921	·883	·845	·808	·771	·735	·700	·665	·630	·596	·563	·530	·497	·464
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 00

A.—7 HOURS.

B.—4 HOURS.

Dec.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·020	·020	·020	·019	·019	·019	·019	·019	·019	·019	·018	·018	·018	·018	·018
2	·040	·040	·039	·039	·039	·038	·038	·038	·037	·037	·037	·037	·037	·036	·036
3	·060	·059	·059	·058	·058	·057	·057	·057	·056	·056	·055	·055	·055	·055	·054
4	·080	·079	·078	·078	·077	·077	·076	·075	·075	·074	·074	·074	·073	·073	·072
5	·100	·099	·098	·097	·097	·096	·095	·094	·094	·093	·093	·092	·091	·091	·091
6°	·120	·119	·118	·117	·116	·115	·114	·113	·113	·112	·111	·111	·110	·109	·109
7	·140	·139	·138	·137	·135	·134	·133	·132	·132	·131	·130	·129	·128	·128	·127
8	·161	·159	·158	·156	·155	·154	·153	·152	·151	·150	·149	·148	·147	·146	·145
9	·181	·179	·178	·176	·175	·173	·172	·171	·170	·169	·168	·167	·166	·165	·164
10	·202	·200	·198	·196	·195	·193	·192	·190	·189	·188	·186	·185	·184	·183	·183
11°	·222	·220	·218	·216	·214	·213	·211	·210	·208	·207	·206	·204	·203	·202	·201
12	·243	·241	·239	·236	·235	·233	·231	·229	·228	·226	·225	·223	·222	·221	·220
13	·264	·261	·259	·257	·255	·253	·251	·249	·247	·246	·244	·243	·241	·240	·239
14	·285	·282	·280	·277	·275	·273	·271	·269	·267	·265	·264	·262	·261	·259	·258
15	·306	·303	·301	·298	·296	·293	·291	·289	·287	·285	·283	·282	·280	·279	·277
16°	·328	·325	·322	·319	·316	·314	·312	·309	·307	·305	·303	·302	·300	·298	·297
17	·350	·346	·343	·340	·337	·335	·332	·330	·327	·325	·323	·321	·320	·318	·317
18	·371	·368	·365	·362	·359	·356	·353	·350	·348	·346	·344	·342	·340	·338	·336
19	·394	·390	·386	·383	·380	·377	·374	·371	·369	·366	·364	·362	·360	·358	·356
20	·416	·412	·408	·405	·402	·398	·395	·393	·390	·387	·385	·383	·381	·379	·377
21°	·439	·435	·431	·427	·424	·420	·417	·414	·411	·408	·406	·404	·401	·399	·397
22	·462	·458	·453	·450	·446	·442	·439	·436	·433	·430	·427	·425	·422	·420	·418
23	·485	·481	·476	·472	·468	·465	·461	·458	·455	·452	·449	·446	·444	·442	·439
24	·509	·504	·500	·495	·491	·487	·484	·480	·477	·474	·471	·468	·466	·463	·461
25	·533	·528	·523	·519	·515	·510	·507	·503	·499	·496	·493	·490	·488	·485	·483
26°	·558	·552	·547	·543	·538	·534	·530	·526	·522	·519	·516	·513	·510	·507	·505
27	·583	·577	·572	·567	·562	·558	·554	·550	·546	·542	·539	·536	·533	·530	·527
28	·608	·602	·597	·592	·587	·582	·578	·573	·570	·566	·562	·559	·556	·553	·550
29	·634	·628	·622	·617	·612	·607	·602	·598	·594	·590	·586	·583	·580	·577	·574
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 0

B.—7 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—4 HOURS.

Stars.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
Fomalhaut	·664	·658	·652	·646	·641	·636	·631	·627	·622	·618	·614	·611	·607	·604	·601
Castor . .	·717	·711	·704	·698	·692	·687	·682	·677	·672	·668	·664	·660	·656	·653	·650
α Columbæ .	·775	·767	·760	·754	·748	·742	·736	·731	·726	·721	·717	·712	·709	·705	·701
Vega. . .	·916	·907	·899	·891	·884	·877	·870	·864	·858	·852	·847	·842	·837	·833	·829
α Phœnicis .	1·061	1·051	1·041	1·032	1·024	1·015	1·008	1·000	·994	·987	·981	·975	·970	·965	·960
α Cygni . .	1·140	1·129	1·119	1·110	1·100	1·092	1·083	1·076	1·068	1·061	1·055	1·049	1·043	1·037	1·032
Capella . .	1·180	1·169	1·158	1·148	1·139	1·130	1·121	1·113	1·105	1·098	1·091	1·085	1·079	1·074	1·068
α Gruis . .	1·246	1·234	1·223	1·212	1·202	1·192	1·183	1·175	1·167	1·159	1·152	1·145	1·139	1·133	1·128
α Persei .	1·339	1·327	1·315	1·303	1·292	1·282	1·273	1·263	1·255	1·247	1·239	1·232	1·225	1·219	1·213
Benetnasch	1·353	1·341	1·328	1·317	1·306	1·296	1·286	1·277	1·268	1·260	1·252	1·245	1·238	1·231	1·225
Canopus .	1·497	1·483	1·470	1·457	1·445	1·434	1·423	1·413	1·403	1·394	1·385	1·377	1·370	1·363	1·356
α Cassiopeiæ	1·695	1·679	1·664	1·649	1·636	1·623	1·610	1·599	1·588	1·577	1·568	1·559	1·550	1·542	1·535
α Pavonis. .	1·765	1·748	1·732	1·717	1·703	1·689	1·677	1·665	1·653	1·642	1·632	1·623	1·614	1·605	1·598
Achernar .	1·812	1·795	1·779	1·763	1·749	1·735	1·722	1·709	1·698	1·687	1·676	1·666	1·657	1·649	1·641
ι Argûs . .	1·892	1·874	1·857	1·841	1·825	1·811	1·797	1·784	1·772	1·761	1·750	1·740	1·730	1·721	1·713
β Centauri .	1·971	1·953	1·935	1·918	1·902	1·887	1·873	1·860	1·847	1·835	1·824	1·813	1·803	1·794	1·785
Dubhe . .	2·177	2·156	2·137	2·118	2·101	2·084	2·068	2·053	2·039	2·026	2·013	2·002	1·991	1·980	1·971
α_1 Crucis .	2·200	2·180	2·160	2·141	2·123	2·107	2·091	2·076	2·061	2·048	2·035	2·023	2·012	2·002	1·992
α Tri. Austr. .	2·955	2·927	2·900	2·875	2·851	2·829	2·807	2·787	2·768	2·750	2·733	2·717	2·702	2·688	2·675
β Urs. Min. .	4·139	4·100	4·063	4·028	3·994	3·963	3·933	3·905	3·878	3·853	3·829	3·806	3·786	3·766	3·748
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 0

B.—7 HOURS.

A.—5 HOURS.

Lat.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·004	·004	·004	·003	·003	·003	·003	·002	·002	·002	·001	·001	·001	·000	·000
2	·009	·008	·007	·007	·006	·006	·005	·004	·004	·003	·002	·002	·001	·001	·000
3	·013	·012	·011	·010	·009	·008	·007	·006	·006	·005	·004	·003	·002	·001	·000
4	·017	·016	·015	·014	·012	·011	·010	·009	·007	·006	·005	·004	·002	·001	·000
5	·022	·020	·019	·017	·015	·014	·012	·011	·009	·008	·006	·005	·003	·002	·000
6°	·026	·024	·022	·020	·019	·017	·015	·013	·011	·009	·007	·006	·004	·002	·000
7	·031	·028	·026	·024	·022	·019	·017	·015	·013	·011	·009	·006	·004	·002	·000
8	·035	·032	·030	·027	·025	·022	·020	·017	·015	·012	·010	·007	·005	·003	·000
9	·039	·037	·034	·031	·028	·025	·022	·019	·017	·014	·011	·008	·006	·003	·000
10	·044	·041	·037	·034	·031	·028	·025	·022	·019	·015	·012	·009	·006	·003	·000
11°	·048	·045	·041	·038	·034	·031	·027	·024	·020	·017	·014	·010	·007	·003	·000
12	·053	·049	·045	·041	·037	·034	·030	·026	·022	·019	·015	·011	·007	·004	·000
13	·058	·053	·049	·045	·041	·037	·032	·028	·024	·020	·016	·012	·008	·004	·000
14	·062	·058	·053	·048	·044	·039	·035	·031	·026	·022	·017	·013	·009	·004	·000
15	·067	·062	·057	·052	·047	·042	·038	·033	·028	·023	·019	·014	·009	·005	·000
16°	·071	·066	·061	·056	·051	·045	·040	·035	·030	·025	·020	·015	·010	·005	·000
17	·076	·071	·065	·059	·054	·048	·043	·038	·032	·027	·021	·016	·011	·005	·000
18	·081	·075	·069	·063	·057	·051	·046	·040	·034	·028	·023	·017	·011	·006	·000
19	·086	·079	·073	·067	·061	·055	·048	·042	·036	·030	·024	·018	·012	·006	·000
20	·091	·084	·077	·071	·064	·058	·051	·045	·038	·032	·025	·019	·013	·006	·000
21°	·096	·089	·082	·075	·068	·061	·054	·047	·040	·034	·027	·020	·013	·007	·000
22	·101	·093	·086	·079	·071	·064	·057	·050	·042	·035	·028	·021	·014	·007	·000
23	·106	·098	·090	·083	·075	·067	·060	·052	·045	·037	·030	·022	·015	·007	·000
24	·111	·103	·095	·087	·079	·071	·063	·055	·047	·039	·031	·023	·016	·008	·000
25	·116	·108	·099	·091	·082	·074	·066	·057	·049	·041	·033	·024	·016	·008	·000
26°	·122	·113	·104	·095	·086	·077	·069	·060	·051	·043	·034	·026	·017	·009	·000
27	·127	·118	·108	·099	·090	·081	·072	·063	·054	·045	·036	·027	·018	·009	·000
28	·133	·123	·113	·103	·094	·084	·075	·065	·056	·047	·037	·028	·019	·009	·000
29	·138	·128	·118	·108	·098	·088	·078	·068	·058	·049	·039	·029	·019	·010	·000
30	·144	·133	·123	·112	·102	·091	·081	·071	·061	·051	·040	·030	·020	·010	·000
31°	·150	·139	·128	·117	·106	·095	·084	·074	·063	·053	·042	·031	·021	·010	·000
32	·156	·144	·133	·121	·110	·099	·088	·077	·066	·055	·044	·033	·022	·011	·000
33	·162	·150	·138	·126	·115	·103	·091	·080	·068	·057	·045	·034	·023	·011	·000
34	·168	·156	·143	·131	·119	·107	·095	·083	·071	·059	·047	·035	·024	·012	·000
35	·175	·162	·149	·136	·123	·111	·098	·086	·074	·061	·049	·037	·024	·012	·000
36°	·181	·168	·154	·141	·128	·115	·102	·089	·076	·064	·051	·038	·025	·013	·000
37	·188	·174	·160	·146	·133	·119	·106	·093	·079	·066	·053	·039	·026	·013	·000
38	·195	·180	·166	·152	·138	·124	·110	·096	·082	·068	·055	·041	·027	·014	·000
39	·202	·187	·172	·157	·143	·128	·114	·099	·085	·071	·057	·042	·028	·014	·000
40	·209	·194	·178	·163	·148	·133	·118	·103	·088	·073	·059	·044	·029	·015	·000
41°	·217	·201	·185	·169	·153	·138	·122	·107	·091	·076	·061	·046	·030	·015	·000
42	·224	·208	·191	·175	·159	·143	·127	·111	·095	·079	·063	·047	·031	·016	·000
43	·233	·215	·198	·181	·164	·148	·131	·114	·098	·082	·065	·049	·033	·016	·000
44	·241	·223	·205	·188	·170	·153	·136	·119	·101	·085	·068	·051	·034	·017	·000
45	·249	·231	·213	·194	·176	·158	·141	·123	·105	·088	·070	·052	·035	·017	·000
46°	·258	·239	·220	·201	·183	·164	·146	·127	·109	·091	·072	·054	·036	·018	·000
47	·267	·248	·228	·208	·189	·170	·151	·132	·113	·094	·075	·056	·037	·019	·000
48	·277	·256	·236	·216	·196	·176	·156	·136	·117	·097	·078	·058	·039	·019	·000
49	·287	·266	·245	·224	·203	·182	·162	·141	·121	·101	·080	·060	·040	·020	·000
50	·297	·275	·253	·232	·210	·189	·167	·146	·125	·104	·083	·062	·042	·021	·000
51°	·308	·285	·262	·240	·218	·196	·174	·152	·130	·108	·086	·065	·043	·022	·000
52	·319	·295	·272	·249	·226	·203	·180	·157	·135	·112	·090	·067	·045	·022	·000
53	·331	·306	·282	·258	·234	·210	·187	·163	·139	·116	·093	·070	·046	·023	·000
54	·343	·318	·293	·268	·243	·218	·193	·169	·145	·120	·096	·072	·048	·024	·000
55	·356	·330	·304	·278	·252	·226	·201	·175	·150	·125	·100	·075	·050	·025	·000
56°	·370	·342	·315	·288	·261	·235	·208	·182	·156	·130	·104	·078	·052	·026	·000
57	·384	·356	·327	·299	·272	·244	·216	·189	·162	·135	·108	·081	·054	·027	·000
58	·399	·369	·340	·311	·282	·253	·225	·196	·168	·140	·112	·084	·056	·028	·000
59	·415	·384	·354	·324	·293	·264	·234	·204	·175	·146	·116	·087	·058	·029	·000
60	·432	·400	·368	·337	·305	·274	·243	·213	·182	·152	·121	·091	·060	·030	·000
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 00

A.—6 HOURS.

B.—5 HOURS.

Dec.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
0°	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000	·000
1	·018	·018	·018	·018	·018	·018	·018	·018	·018	·018	·017	·017	·017	·017	·017
2	·036	·036	·036	·036	·035	·035	·035	·035	·035	·035	·035	·035	·035	·035	·035
3	·054	·054	·054	·053	·053	·053	·053	·053	·053	·053	·053	·052	·052	·052	·052
4	·072	·072	·071	·071	·071	·071	·071	·071	·070	·070	·070	·070	·070	·070	·070
5	·090	·090	·089	·089	·089	·089	·088	·088	·088	·088	·088	·088	·088	·088	·087
6°	·108	·108	·107	·107	·107	·106	·106	·106	·106	·106	·105	·105	·105	·105	·105
7	·127	·126	·126	·125	·125	·124	·124	·124	·123	·123	·123	·123	·123	·123	·123
8	·145	·144	·144	·143	·143	·142	·142	·142	·141	·141	·141	·141	·141	·141	·141
9	·163	·163	·162	·161	·161	·160	·160	·160	·159	·159	·159	·159	·158	·158	·158
10	·182	·181	·180	·180	·179	·179	·178	·178	·177	·177	·177	·177	·176	·176	·176
11°	·200	·199	·199	·198	·197	·197	·196	·196	·195	·195	·195	·195	·194	·194	·194
12	·219	·218	·217	·217	·216	·215	·215	·214	·214	·213	·213	·213	·213	·213	·213
13	·238	·237	·236	·235	·234	·234	·233	·233	·232	·232	·231	·231	·231	·231	·231
14	·257	·256	·255	·254	·253	·252	·252	·251	·251	·250	·250	·250	·249	·249	·249
15	·276	·275	·274	·273	·272	·271	·271	·270	·269	·269	·269	·268	·268	·268	·268
16°	·296	·294	·293	·292	·291	·290	·290	·289	·288	·288	·287	·287	·287	·287	·287
17	·315	·314	·313	·311	·310	·310	·309	·308	·307	·307	·306	·306	·306	·306	·306
18	·335	·333	·332	·331	·330	·329	·328	·327	·327	·326	·326	·325	·325	·325	·325
19	·355	·353	·352	·351	·350	·349	·348	·347	·346	·346	·345	·345	·345	·344	·344
20	·375	·374	·372	·371	·370	·369	·368	·367	·366	·365	·365	·364	·364	·364	·364
21°	·396	·394	·392	·391	·390	·389	·388	·387	·386	·385	·385	·384	·384	·384	·384
22	·416	·415	·413	·412	·410	·409	·408	·407	·406	·406	·405	·405	·404	·404	·404
23	·437	·436	·434	·432	·431	·430	·429	·428	·427	·426	·426	·425	·425	·425	·424
24	·459	·457	·455	·454	·452	·451	·450	·449	·448	·447	·446	·446	·446	·445	·445
25	·481	·479	·477	·475	·474	·472	·471	·470	·469	·468	·467	·467	·467	·466	·466
26°	·503	·501	·499	·497	·495	·494	·493	·491	·490	·490	·489	·488	·488	·488	·488
27	·525	·523	·521	·519	·517	·516	·515	·513	·512	·511	·511	·510	·510	·510	·510
28	·548	·546	·544	·542	·540	·538	·537	·536	·535	·534	·533	·532	·532	·532	·532
29	·571	·569	·567	·565	·563	·561	·560	·558	·557	·556	·556	·555	·555	·554	·554
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 0

B.—6 HOURS.

Useful ultra-Zodiacal Stars of 1st and 2nd mags. in order of Declination.

B.—5 HOURS.

Stars.	m. 4	m. 8	m. 12	m. 16	m. 20	m. 24	m. 28	m. 32	m. 36	m. 40	m. 44	m. 48	m. 52	m. 56	m. 60
Fomalhaut	·599	·596	·594	·592	·590	·588	·587	·585	·584	·583	·582	·582	·581	·581	·581
Castor	·647	·644	·642	·639	·637	·635	·634	·632	·631	·630	·629	·628	·628	·628	·628
α Columbæ	·698	·695	·693	·690	·688	·686	·684	·683	·681	·680	·679	·679	·678	·678	·678
Vega	·825	·822	·819	·816	·813	·811	·809	·807	·805	·804	·803	·802	·801	·801	·801
α Phœnicis	·956	·952	·948	·945	·942	·939	·937	·935	·933	·931	·930	·929	·928	·928	·928
α Cygni	1·028	1·023	1·020	1·016	1·013	1·010	1·007	1·005	1·003	1·001	1·000	·999	·998	·997	·997
Capella	1·064	1·059	1·055	1·051	1·048	1·045	1·042	1·040	1·038	1·036	1·034	1·033	1·033	1·032	1·032
α Gruis	1·123	1·118	1·114	1·110	1·106	1·103	1·100	1·098	1·095	1·094	1·092	1·091	1·090	1·090	1·089
α Persei	1·207	1·202	1·198	1·193	1·189	1·186	1·183	1·180	1·178	1·176	1·174	1·173	1·172	1·172	1·171
Benetnasch	1·220	1·215	1·210	1·206	1·202	1·198	1·195	1·193	1·190	1·188	1·187	1·185	1·184	1·184	1·184
Canopus	1·350	1·344	1·339	1·334	1·330	1·326	1·323	1·320	1·317	1·315	1·313	1·312	1·311	1·310	1·310
α Cassiopeiæ	1·528	1·521	1·515	1·510	1·505	1·501	1·497	1·493	1·490	1·488	1·486	1·484	1·483	1·483	1·482
α Pavonis	1·591	1·584	1·578	1·572	1·567	1·563	1·558	1·555	1·552	1·549	1·547	1·545	1·544	1·544	1·543
Achernar	1·633	1·627	1·620	1·615	1·609	1·605	1·600	1·597	1·594	1·591	1·589	1·587	1·586	1·585	1·585
ι Argûs	1·705	1·698	1·691	1·685	1·680	1·675	1·671	1·667	1·664	1·661	1·658	1·657	1·655	1·655	1·654
β Centauri	1·777	1·770	1·763	1·756	1·751	1·746	1·741	1·737	1·734	1·731	1·728	1·727	1·725	1·724	1·724
Dubhe	1·962	1·954	1·946	1·939	1·933	1·927	1·922	1·918	1·914	1·911	1·908	1·906	1·905	1·904	1·904
α¹ Crucis	1·983	1·975	1·967	1·960	1·954	1·948	1·943	1·939	1·935	1·932	1·929	1·927	1·926	1·925	1·924
α Tri. Austr.	2·663	2·652	2·642	2·633	2·624	2·616	2·610	2·604	2·599	2·594	2·591	2·588	2·586	2·585	2·584
β Urs. Min.	3·731	3·715	3·701	3·688	3·676	3·665	3·656	3·647	3·640	3·634	3·629	3·625	3·622	3·621	3·620
	m. 56	m. 52	m. 48	m. 44	m. 40	m. 36	m. 32	m. 28	m. 24	m. 20	m. 16	m. 12	m. 8	m. 4	m. 0

B.—6 HOURS.

C.

The subjoined quantities shew the error produced in the Longitude by an error of 1′ in the Latitude
They represent the sum or difference of the A and B values.

Lat.	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°
	TRUE AZIMUTH.														
0°	57·29	28·64	19·08	14·30	11·43	9·514	8·144	7·115	6·314	5·671	5·145	4·705	4·331	4·011	3·732
1	57·30	28·64	19·08	14·30	11·43	9·516	8·146	7·116	6·315	5·672	5·145	4·705	4·332	4·011	3·733
2	57·32	28·65	19·09	14·31	11·44	9·520	8·149	7·120	6·318	5·675	5·148	4·707	4·334	4·013	3·734
3	57·37	28·68	19·11	14·32	11·45	9·527	8·156	7·125	6·322	5·679	5·152	4·711	4·337	4·016	3·737
4	57·43	28·71	19·13	14·34	11·46	9·538	8·164	7·133	6·329	5·685	5·157	4·716	4·342	4·021	3·741
5	57·51	28·75	19·15	14·36	11·47	9·551	8·175	7·143	6·338	5·693	5·164	4·723	4·348	4·026	3·746
6	57·61	28·79	19·19	14·38	11·49	9·567	8·189	7·155	6·349	5·703	5·173	4·731	4·355	4·033	3·753
7	57·72	28·85	19·22	14·41	11·52	9·586	8·206	7·169	6·361	5·714	5·183	4·740	4·364	4·041	3·760
8	57·85	28·92	19·27	14·44	11·54	9·608	8·224	7·185	6·376	5·727	5·195	4·751	4·374	4·050	3·769
9	58·00	28·99	19·32	14·48	11·57	9·633	8·246	7·204	6·392	5·742	5·209	4·763	4·385	4·061	3·779
10	58·17	29·08	19·38	14·52	11·61	9·661	8·270	7·225	6·411	5·759	5·224	4·777	4·398	4·073	3·790
11	58·36	29·17	19·44	14·57	11·64	9·692	8·297	7·249	6·432	5·777	5·241	4·793	4·413	4·086	3·802
12	58·57	29·28	19·51	14·62	11·69	9·727	8·326	7·274	6·455	5·798	5·259	4·810	4·428	4·100	3·815
13	58·80	29·39	19·58	14·68	11·73	9·765	8·359	7·303	6·480	5·820	5·280	4·828	4·445	4·116	3·830
14	59·04	29·51	19·67	14·74	11·78	9·806	8·394	7·333	6·507	5·845	5·302	4·849	4·464	4·134	3·846
15	59·31	29·65	19·75	14·81	11·83	9·850	8·432	7·366	6·536	5·871	5·326	4·871	4·484	4·152	3·864
16	59·60	29·79	19·85	14·88	11·89	9·898	8·473	7·402	6·568	5·900	5·352	4·894	4·506	4·172	3·882
17	59·91	29·94	19·95	14·95	11·95	9·949	8·516	7·440	6·602	5·930	5·380	4·920	4·529	4·194	3·903
18	60·24	30·11	20·06	15·04	12·02	10·00	8·563	7·482	6·639	5·963	5·409	4·947	4·554	4·217	3·924
19	60·59	30·29	20·18	15·12	12·09	10·06	8·614	7·525	6·678	5·998	5·441	4·976	4·581	4·242	3·947
20	60·97	30·47	20·31	15·22	12·16	10·12	8·667	7·572	6·719	6·035	5·475	5·007	4·609	4·268	3·972
21	61·37	30·67	20·44	15·32	12·24	10·19	8·724	7·622	6·763	6·075	5·511	5·039	4·640	4·296	3·998
22	61·79	30·89	20·58	15·42	12·33	10·26	8·784	7·674	6·810	6·117	5·549	5·074	4·672	4·326	4·025
23	62·24	31·11	20·73	15·54	12·42	10·34	8·848	7·730	6·859	6·161	5·589	5·111	4·706	4·357	4·054
24	62·71	31·35	20·89	15·65	12·51	10·41	8·915	7·789	6·911	6·208	5·631	5·150	4·741	4·390	4·085
25	63·21	31·60	21·05	15·78	12·61	10·50	8·986	7·851	6·966	6·258	5·676	5·191	4·779	4·425	4·118
26	63·74	31·86	21·23	15·91	12·72	10·59	9·061	7·917	7·025	6·310	5·724	5·234	4·819	4·462	4·152
27	64·30	32·14	21·42	16·05	12·83	10·68	9·141	7·986	7·086	6·365	5·774	5·280	4·861	4·501	4·189
28	64·88	32·43	21·61	16·20	12·95	10·78	9·224	8·059	7·151	6·423	5·827	5·328	4·906	4·542	4·227
29	65·50	32·74	21·82	16·35	13·07	10·88	9·312	8·135	7·219	6·484	5·882	5·379	4·952	4·586	4·267
30	66·15	33·07	22·03	16·51	13·20	10·99	9·404	8·216	7·290	6·549	5·940	5·432	5·002	4·631	4·309
31	66·84	33·41	22·26	16·68	13·33	11·10	9·501	8·301	7·366	6·616	6·002	5·489	5·053	4·679	4·354
32	67·56	33·77	22·50	16·86	13·48	11·22	9·604	8·390	7·445	6·687	6·066	5·548	5·108	4·729	4·401
33	68·31	34·14	22·75	17·05	13·63	11·34	9·711	8·484	7·528	6·762	6·134	5·610	5·165	4·782	4·450
34	69·10	34·54	23·02	17·25	13·79	11·48	9·824	8·583	7·616	6·841	6·205	5·675	5·225	4·838	4·502
35	69·94	34·96	23·29	17·46	13·95	11·61	9·942	8·686	7·708	6·923	6·280	5·743	5·288	4·896	4·556
36	70·81	35·40	23·59	17·68	14·13	11·76	10·07	8·795	7·804	7·010	6·359	5·815	5·354	4·958	4·613
37	71·73	35·86	23·89	17·91	14·31	11·91	10·20	8·909	7·906	7·101	6·442	5·891	5·424	5·022	4·673
38	72·70	36·34	24·21	18·15	14·50	12·07	10·34	9·030	8·012	7·197	6·529	5·970	5·497	5·090	4·736
39	73·72	36·85	24·55	18·40	14·71	12·24	10·48	9·156	8·124	7·298	6·620	6·054	5·574	5·161	4·802
40	74·79	37·38	24·91	18·67	14·92	12·42	10·63	9·288	8·242	7·403	6·716	6·141	5·654	5·236	4·872
41	75·91	37·94	25·28	18·95	15·14	12·61	10·79	9·428	8·366	7·515	6·817	6·234	5·739	5·314	4·945
42	77·09	38·53	25·68	19·24	15·38	12·80	10·96	9·575	8·496	7·631	6·923	6·331	5·829	5·397	5·022
43	78·33	39·16	26·09	19·55	15·63	13·01	11·14	9·729	8·633	7·754	7·034	6·433	5·923	5·484	5·103
44	79·64	39·81	26·53	19·88	15·89	13·23	11·32	9·892	8·777	7·884	7·152	6·540	6·021	5·576	5·188
45	81·02	40·50	26·98	20·22	16·16	13·46	11·52	10·06	8·929	8·020	7·275	6·653	6·126	5·672	5·278
46	82·47	41·22	27·47	20·59	16·45	13·70	11·72	10·24	9·089	8·164	7·406	6·773	6·235	5·774	5·372
47	84·00	41·99	27·98	20·97	16·76	13·95	11·94	10·43	9·258	8·316	7·543	6·898	6·351	5·881	5·472
48	85·62	42·80	28·52	21·37	17·08	14·22	12·17	10·63	9·436	8·476	7·688	7·031	6·473	5·994	5·577
49	87·32	43·65	29·08	21·80	17·42	14·50	12·41	10·85	9·624	8·644	7·842	7·171	6·602	6·113	5·689
50	89·13	44·55	29·68	22·25	17·78	14·80	12·67	11·07	9·822	8·823	8·004	7·319	6·739	6·240	5·806
51	91·03	45·50	30·32	22·72	18·16	15·12	12·94	11·31	10·03	9·012	8·175	7·476	6·883	6·373	5·930
52	93·05	46·51	30·99	23·23	18·57	15·45	13·23	11·56	10·26	9·212	8·356	7·642	7·035	6·515	6·062
53	95·20	47·58	31·71	23·76	18·99	15·81	13·53	11·82	10·49	9·424	8·548	7·817	7·197	6·664	6·201
54	97·47	48·72	32·46	24·33	19·45	16·19	13·86	12·11	10·74	9·649	8·752	8·004	7·369	6·824	6·349
55	99·88	49·93	33·27	24·93	19·93	16·59	14·20	12·41	11·01	9·888	8·969	8·202	7·552	6·993	6·507
56	102·5	51·21	34·12	25·57	20·44	17·01	14·56	12·72	11·29	10·14	9·200	8·413	7·746	7·172	6·674
57	105·2	52·58	35·03	26·26	20·99	17·47	14·95	13·06	11·59	10·41	9·446	8·638	7·953	7·364	6·852
58	108·1	54·04	36·01	26·99	21·57	17·95	15·37	13·43	11·91	10·70	9·708	8·878	8·174	7·569	7·043
59	111·2	55·60	37·05	27·77	22·19	18·47	15·81	13·82	12·26	11·01	9·989	9·135	8·410	7·787	7·246
60	114·6	57·27	38·16	28·60	22·86	19·03	16·29	14·23	12·63	11·34	10·29	9·409	8·663	8·022	7·464

To name Azimuth { In North latitude put **N** for a – 'Error,' and **S** for a + 'Error.'
In South latitude put **S** for a – 'Error,' and **N** for a + 'Error.'

C.

The subjoined quantities shew the error produced in the Longitude by an error of 1′ in the Latitude
They represent the sum or difference of the A and B values.

Lat.	TRUE AZIMUTH.														
	16°	17°	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°
0°	3·487	3·271	3·078	2·904	2·747	2·605	2·475	2·356	2·246	2·145	2·050	1·963	1·881	1·804	1·732
1	3·488	3·271	3·078	2·905	2·748	2·605	2·475	2·356	2·246	2·145	2·051	1·963	1·881	1·804	1·732
2	3·490	3·273	3·080	2·906	2·749	2·607	2·477	2·357	2·247	2·146	2·052	1·964	1·882	1·805	1·733
3	3·492	3·275	3·082	2·908	2·751	2·609	2·478	2·359	2·249	2·147	2·053	1·965	1·883	1·807	1·734
4	3·496	3·279	3·085	2·911	2·754	2·611	2·481	2·362	2·252	2·150	2·055	1·967	1·885	1·808	1·736
5	3·501	3·283	3·089	2·915	2·758	2·615	2·485	2·365	2·255	2·153	2·058	1·970	1·888	1·811	1·739
6°	3·507	3·289	3·095	2·920	2·763	2·619	2·489	2·369	2·258	2·156	2·062	1·973	1·891	1·814	1·742
7	3·514	3·295	3·101	2·926	2·768	2·625	2·494	2·374	2·263	2·161	2·066	1·977	1·895	1·818	1·745
8	3·522	3·303	3·108	2·933	2·774	2·631	2·499	2·379	2·268	2·166	2·070	1·982	1·899	1·822	1·749
9	3·531	3·312	3·116	2·940	2·782	2·638	2·506	2·385	2·274	2·171	2·076	1·987	1·904	1·827	1·754
10	3·541	3·321	3·125	2·949	2·790	2·645	2·513	2·392	2·281	2·178	2·082	1·993	1·910	1·832	1·759
11°	3·553	3·332	3·135	2·959	2·799	2·654	2·521	2·400	2·288	2·185	2·089	1·999	1·916	1·838	1·764
12	3·565	3·344	3·146	2·969	2·809	2·663	2·530	2·408	2·296	2·192	2·096	2·006	1·923	1·844	1·771
13	3·579	3·357	3·159	2·981	2·820	2·674	2·540	2·418	2·305	2·201	2·104	2·014	1·930	1·852	1·778
14	3·594	3·371	3·172	2·993	2·832	2·685	2·551	2·428	2·315	2·210	2·113	2·023	1·938	1·859	1·785
15	3·610	3·386	3·186	3·007	2·844	2·697	2·562	2·439	2·325	2·220	2·123	2·032	1·947	1·868	1·793
16°	3·628	3·403	3·202	3·021	2·858	2·710	2·575	2·451	2·337	2·231	2·133	2·042	1·957	1·877	1·802
17	3·647	3·420	3·218	3·037	2·873	2·724	2·588	2·463	2·349	2·242	2·144	2·052	1·967	1·886	1·811
18	3·667	3·439	3·236	3·054	2·889	2·739	2·602	2·477	2·362	2·255	2·156	2·064	1·978	1·897	1·821
19	3·688	3·459	3·255	3·072	2·906	2·755	2·618	2·492	2·375	2·268	2·168	2·076	1·989	1·908	1·832
20	3·711	3·481	3·275	3·091	2·924	2·772	2·634	2·507	2·390	2·282	2·182	2·089	2·001	1·920	1·843
21°	3·736	3·504	3·297	3·111	2·943	2·790	2·651	2·523	2·406	2·297	2·196	2·102	2·015	1·932	1·855
22	3·761	3·528	3·319	3·132	2·963	2·810	2·669	2·541	2·422	2·313	2·211	2·117	2·028	1·946	1·868
23	3·789	3·553	3·343	3·155	2·985	2·830	2·689	2·559	2·440	2·330	2·227	2·132	2·043	1·960	1·882
24	3·817	3·580	3·369	3·179	3·007	2·852	2·709	2·579	2·459	2·347	2·244	2·148	2·059	1·975	1·896
25	3·848	3·609	3·396	3·204	3·032	2·874	2·731	2·599	2·478	2·366	2·262	2·166	2·075	1·991	1·911
26°	3·880	3·639	3·424	3·231	3·057	2·898	2·754	2·621	2·499	2·386	2·281	2·184	2·092	2·007	1·927
27	3·914	3·671	3·454	3·259	3·084	2·924	2·778	2·644	2·521	2·407	2·301	2·203	2·111	2·025	1·944
28	3·950	3·704	3·486	3·289	3·112	2·950	2·803	2·668	2·544	2·429	2·322	2·223	2·130	2·043	1·962
29	3·987	3·740	3·519	3·321	3·141	2·979	2·830	2·694	2·568	2·452	2·344	2·244	2·150	2·063	1·980
30	4·027	3·777	3·554	3·353	3·173	3·008	2·858	2·720	2·594	2·476	2·367	2·266	2·172	2·083	2·000
31°	4·069	3·816	3·591	3·388	3·205	3·039	2·888	2·748	2·620	2·502	2·392	2·290	2·194	2·105	2·021
32	4·112	3·857	3·629	3·425	3·240	3·072	2·919	2·778	2·648	2·529	2·418	2·314	2·218	2·127	2·042
33	4·158	3·900	3·670	3·463	3·276	3·106	2·951	2·809	2·678	2·557	2·445	2·340	2·243	2·151	2·065
34	4·207	3·945	3·712	3·503	3·314	3·142	2·985	2·842	2·709	2·587	2·473	2·367	2·269	2·176	2·089
35	4·257	3·993	3·757	3·545	3·354	3·180	3·022	2·876	2·742	2·618	2·503	2·396	2·296	2·202	2·114
36°	4·311	4·043	3·804	3·590	3·396	3·220	3·059	2·912	2·776	2·651	2·534	2·426	2·325	2·230	2·141
37	4·367	4·096	3·854	3·636	3·440	3·262	3·099	2·950	2·812	2·685	2·567	2·457	2·355	2·259	2·169
38	4·426	4·151	3·906	3·685	3·487	3·306	3·141	2·990	2·850	2·721	2·602	2·491	2·387	2·289	2·198
39	4·487	4·209	3·960	3·737	3·535	3·352	3·185	3·031	2·890	2·759	2·638	2·525	2·420	2·321	2·229
40	4·552	4·270	4·018	3·791	3·587	3·401	3·231	3·075	2·932	2·799	2·676	2·562	2·455	2·355	2·261
41°	4·621	4·334	4·078	3·848	3·640	3·452	3·280	3·122	2·976	2·841	2·717	2·600	2·492	2·390	2·295
42	4·693	4·401	4·141	3·908	3·697	3·505	3·331	3·170	3·022	2·886	2·759	2·641	2·531	2·428	2·331
43	4·768	4·472	4·208	3·971	3·757	3·562	3·384	3·221	3·071	2·932	2·803	2·684	2·572	2·467	2·368
44	4·848	4·547	4·278	4·037	3·819	3·622	3·441	3·275	3·122	2·981	2·850	2·728	2·615	2·508	2·408
45	4·932	4·626	4·353	4·107	3·886	3·684	3·500	3·332	3·176	3·033	2·900	2·776	2·660	2·551	2·449
46°	5·020	4·709	4·431	4·181	3·955	3·750	3·563	3·391	3·233	3·087	2·952	2·825	2·707	2·597	2·493
47	5·114	4·796	4·513	4·258	4·029	3·820	3·629	3·454	3·293	3·144	3·006	2·878	2·758	2·645	2·540
48	5·212	4·888	4·600	4·340	4·106	3·893	3·699	3·521	3·357	3·205	3·064	2·933	2·811	2·696	2·589
49	5·316	4·986	4·691	4·427	4·188	3·971	3·773	3·591	3·424	3·269	3·125	2·992	2·867	2·750	2·640
50	5·425	5·089	4·788	4·518	4·274	4·053	3·851	3·665	3·494	3·336	3·190	3·053	2·926	2·807	2·695
51°	5·542	5·197	4·890	4·615	4·366	4·140	3·933	3·743	3·569	3·408	3·258	3·119	2·989	2·867	2·752
52	5·665	5·313	4·999	4·717	4·463	4·231	4·020	3·827	3·648	3·483	3·330	3·188	3·055	2·930	2·813
53	5·795	5·435	5·114	4·826	4·565	4·329	4·113	3·915	3·732	3·563	3·407	3·261	3·125	2·998	2·878
54	5·933	5·565	5·236	4·941	4·674	4·432	4·211	4·008	3·821	3·648	3·488	3·339	3·200	3·069	2·947
55	6·080	5·703	5·366	5·063	4·790	4·542	4·315	4·107	3·916	3·739	3·575	3·422	3·279	3·145	3·020
56°	6·237	5·849	5·504	5·194	4·913	4·659	4·426	4·213	4·017	3·835	3·667	3·510	3·363	3·226	3·097
57	6·403	6·006	5·651	5·332	5·045	4·783	4·544	4·326	4·124	3·937	3·765	3·604	3·453	3·312	3·180
58	6·581	6·172	5·808	5·480	5·185	4·916	4·671	4·446	4·238	4·047	3·869	3·704	3·549	3·404	3·269
59	6·771	6·351	5·976	5·639	5·335	5·058	4·806	4·574	4·361	4·164	3·981	3·811	3·652	3·503	3·363
60	6·975	6·542	6·155	5·808	5·495	5·210	4·950	4·712	4·492	4·289	4·101	3·925	3·761	3·608	3·464

To name Azimuth { **In North latitude put N for a − 'Error,' and S for a + 'Error.'**
In South latitude put S for a − 'Error,' and N for a + 'Error.' }

C.

The subjoined quantities shew the error produced in the Longitude by an error of 1′ in the Latitude. They represent the sum or difference of the A and B values.

Lat.	TRUE AZIMUTH.														
	31°	32°	33°	34°	35°	36°	37°	38°	39°	40°	41°	42°	43°	44°	45°
0°	1.664	1.600	1.540	1.483	1.428	1.376	1.327	1.280	1.235	1.192	1.150	1.111	1.072	1.036	1.000
1	1.665	1.601	1.540	1.483	1.428	1.377	1.327	1.280	1.235	1.192	1.151	1.111	1.073	1.036	1.000
2	1.665	1.601	1.541	1.483	1.429	1.377	1.328	1.281	1.236	1.192	1.151	1.111	1.073	1.036	1.001
3	1.667	1.603	1.542	1.485	1.430	1.378	1.329	1.282	1.237	1.193	1.152	1.112	1.074	1.037	1.001
4	1.668	1.604	1.544	1.486	1.432	1.380	1.330	1.283	1.238	1.195	1.153	1.113	1.075	1.038	1.002
5	1.671	1.606	1.546	1.488	1.434	1.382	1.332	1.285	1.240	1.196	1.155	1.115	1.076	1.039	1.004
6°	1.673	1.609	1.548	1.491	1.436	1.384	1.334	1.287	1.242	1.198	1.157	1.117	1.078	1.041	1.006
7	1.677	1.612	1.551	1.494	1.439	1.387	1.337	1.290	1.244	1.201	1.159	1.119	1.080	1.043	1.008
8	1.681	1.616	1.555	1.497	1.442	1.390	1.340	1.293	1.247	1.203	1.162	1.122	1.083	1.046	1.010
9	1.685	1.620	1.559	1.501	1.446	1.394	1.344	1.296	1.250	1.207	1.165	1.124	1.086	1.048	1.012
10	1.690	1.625	1.564	1.505	1.450	1.398	1.348	1.300	1.254	1.210	1.168	1.128	1.089	1.052	1.015
11°	1.695	1.630	1.569	1.510	1.455	1.402	1.352	1.304	1.258	1.214	1.172	1.131	1.092	1.055	1.019
12	1.701	1.636	1.574	1.516	1.460	1.407	1.357	1.309	1.262	1.218	1.176	1.135	1.096	1.059	1.022
13	1.708	1.642	1.580	1.522	1.466	1.413	1.362	1.314	1.267	1.223	1.181	1.140	1.101	1.063	1.026
14	1.715	1.649	1.587	1.528	1.472	1.419	1.368	1.319	1.273	1.228	1.186	1.145	1.105	1.067	1.031
15	1.723	1.657	1.594	1.535	1.479	1.425	1.374	1.325	1.278	1.234	1.191	1.150	1.110	1.072	1.035
16°	1.731	1.665	1.602	1.542	1.486	1.432	1.381	1.332	1.285	1.240	1.197	1.155	1.116	1.077	1.040
17	1.740	1.673	1.610	1.550	1.493	1.439	1.388	1.338	1.291	1.246	1.203	1.161	1.121	1.083	1.046
18	1.750	1.683	1.619	1.559	1.502	1.447	1.395	1.346	1.298	1.253	1.210	1.168	1.128	1.089	1.051
19	1.760	1.693	1.629	1.568	1.510	1.456	1.404	1.354	1.306	1.260	1.217	1.175	1.134	1.095	1.058
20	1.771	1.703	1.639	1.578	1.520	1.465	1.412	1.362	1.314	1.268	1.224	1.182	1.141	1.102	1.004
21°	1.783	1.714	1.649	1.588	1.530	1.474	1.421	1.371	1.323	1.277	1.232	1.190	1.149	1.109	1.071
22	1.795	1.726	1.661	1.599	1.540	1.484	1.431	1.380	1.332	1.285	1.241	1.198	1.157	1.117	1.079
23	1.808	1.739	1.673	1.611	1.551	1.495	1.442	1.390	1.342	1.295	1.250	1.207	1.165	1.125	1.086
24	1.822	1.752	1.686	1.623	1.563	1.507	1.453	1.401	1.352	1.305	1.259	1.216	1.174	1.134	1.095
25	1.836	1.766	1.699	1.636	1.576	1.519	1.464	1.412	1.363	1.315	1.269	1.225	1.183	1.143	1.103
26°	1.852	1.781	1.713	1.650	1.589	1.531	1.476	1.424	1.374	1.326	1.280	1.236	1.193	1.152	1.113
27	1.868	1.796	1.728	1.664	1.603	1.545	1.489	1.437	1.386	1.338	1.291	1.246	1.204	1.162	1.122
28	1.885	1.812	1.744	1.679	1.617	1.559	1.503	1.450	1.399	1.350	1.303	1.258	1.215	1.173	1.133
29	1.903	1.830	1.761	1.695	1.633	1.574	1.517	1.463	1.412	1.363	1.315	1.270	1.226	1.184	1.143
30	1.922	1.848	1.778	1.712	1.649	1.589	1.532	1.478	1.426	1.376	1.328	1.282	1.238	1.196	1.155
31°	1.942	1.867	1.796	1.730	1.666	1.606	1.548	1.493	1.441	1.390	1.342	1.296	1.251	1.208	1.167
32	1.962	1.887	1.816	1.748	1.684	1.623	1.565	1.509	1.456	1.405	1.356	1.310	1.265	1.221	1.179
33	1.984	1.908	1.836	1.768	1.703	1.641	1.582	1.526	1.472	1.421	1.372	1.324	1.279	1.235	1.192
34	2.007	1.930	1.857	1.788	1.723	1.660	1.601	1.544	1.490	1.438	1.388	1.340	1.294	1.249	1.206
35	2.032	1.954	1.880	1.810	1.743	1.680	1.620	1.563	1.508	1.455	1.404	1.356	1.309	1.264	1.221
36°	2.057	1.978	1.903	1.833	1.765	1.701	1.640	1.582	1.526	1.473	1.422	1.373	1.326	1.280	1.236
37	2.084	2.004	1.928	1.856	1.788	1.723	1.662	1.603	1.546	1.492	1.440	1.391	1.343	1.297	1.252
38	2.112	2.031	1.954	1.881	1.812	1.747	1.684	1.624	1.567	1.512	1.460	1.409	1.361	1.314	1.269
39	2.142	2.059	1.981	1.908	1.838	1.771	1.708	1.647	1.589	1.534	1.480	1.429	1.380	1.333	1.287
40	2.173	2.089	2.010	1.935	1.864	1.797	1.732	1.671	1.612	1.556	1.502	1.450	1.400	1.352	1.305
41°	2.205	2.120	2.040	1.964	1.892	1.824	1.758	1.696	1.636	1.579	1.524	1.472	1.421	1.372	1.325
42	2.240	2.153	2.072	1.995	1.922	1.852	1.786	1.722	1.662	1.604	1.548	1.494	1.443	1.393	1.346
43	2.276	2.188	2.105	2.027	1.953	1.882	1.815	1.750	1.689	1.630	1.573	1.519	1.466	1.416	1.367
44	2.314	2.225	2.141	2.061	1.985	1.913	1.845	1.779	1.717	1.657	1.599	1.544	1.491	1.440	1.390
45	2.354	2.263	2.178	2.097	2.020	1.946	1.877	1.810	1.746	1.685	1.627	1.571	1.517	1.464	1.414
46°	2.396	2.304	2.217	2.134	2.056	1.981	1.910	1.843	1.778	1.716	1.656	1.599	1.544	1.491	1.440
47	2.440	2.347	2.258	2.174	2.094	2.018	1.946	1.877	1.811	1.747	1.687	1.628	1.572	1.518	1.466
48	2.487	2.392	2.301	2.216	2.134	2.057	1.983	1.913	1.846	1.781	1.719	1.660	1.603	1.548	1.494
49	2.537	2.439	2.347	2.260	2.177	2.098	2.023	1.951	1.882	1.817	1.753	1.693	1.635	1.578	1.524
50	2.589	2.490	2.396	2.306	2.222	2.141	2.065	1.991	1.921	1.854	1.790	1.728	1.668	1.611	1.556
51°	2.645	2.543	2.447	2.356	2.269	2.187	2.109	2.034	1.962	1.894	1.828	1.765	1.704	1.645	1.589
52	2.703	2.599	2.501	2.408	2.320	2.236	2.155	2.079	2.006	1.936	1.869	1.804	1.742	1.682	1.624
53	2.765	2.659	2.559	2.463	2.373	2.287	2.205	2.127	2.052	1.980	1.911	1.845	1.782	1.721	1.602
54	2.831	2.723	2.620	2.522	2.430	2.342	2.258	2.178	2.101	2.028	1.957	1.889	1.824	1.702	1.701
55	2.902	2.790	2.685	2.585	2.490	2.400	2.314	2.232	2.153	2.078	2.006	1.936	1.870	1.805	1.743
56°	2.976	2.862	2.754	2.651	2.554	2.461	2.373	2.289	2.208	2.131	2.057	1.986	1.918	1.852	1.788
57	3.056	2.938	2.827	2.722	2.622	2.527	2.437	2.350	2.267	2.188	2.112	2.039	1.909	1.901	1.836
58	3.141	3.020	2.906	2.798	2.695	2.597	2.504	2.415	2.330	2.249	2.171	2.096	2.024	1.954	1.887
59	3.231	3.107	2.990	2.879	2.773	2.672	2.577	2.485	2.398	2.314	2.234	2.156	2.082	2.011	1.942
60	3.320	3.201	3.080	2.965	2.856	2.753	2.654	2.560	2.470	2.384	2.301	2.221	2.145	2.071	2.000

To name Azimuth { **In North latitude put N for a – 'Error,' and S for a + 'Error.'**
{ **In South latitude put S for a – 'Error,' and N for a + 'Error.'**

C.

The subjoined quantities shew the error produced in the Longitude by an error of 1′ in the Latitude. They represent the sum or difference of the A and B values.

Lat.	TRUE AZIMUTH.														
	46°	47°	48°	49°	50°	51°	52°	53°	54°	55°	56°	57°	58°	59°	60°
0°	·966	·933	·900	·869	·839	·810	·781	·754	·727	·700	·675	·649	·625	·601	·577
1	·966	·933	·901	·869	·839	·810	·781	·754	·727	·700	·675	·650	·625	·601	·577
2	·966	·933	·901	·870	·840	·810	·782	·754	·727	·701	·675	·650	·625	·601	·578
3	·967	·934	·902	·870	·840	·811	·782	·755	·728	·701	·675	·650	·626	·602	·578
4	·968	·935	·903	·871	·841	·812	·783	·755	·728	·702	·676	·651	·626	·602	·579
5	·969	·936	·904	·873	·842	·813	·784	·756	·729	·703	·677	·652	·627	·603	·580
6°	·971	·938	·905	·874	·844	·814	·786	·758	·731	·704	·678	·653	·628	·604	·581
7	·973	·940	·907	·876	·845	·816	·787	·759	·732	·705	·680	·654	·630	·605	·582
8	·975	·942	·909	·878	·847	·818	·789	·761	·734	·707	·681	·656	·631	·607	·583
9	·978	·944	·912	·880	·850	·820	·791	·763	·736	·709	·683	·658	·633	·608	·585
10	·981	·947	·914	·883	·852	·822	·793	·765	·738	·711	·685	·659	·635	·610	·586
11°	·984	·950	·917	·886	·855	·825	·796	·768	·740	·713	·687	·662	·637	·612	·588
12	·987	·953	·921	·889	·858	·828	·799	·770	·743	·716	·690	·664	·639	·614	·590
13	·991	·957	·924	·892	·861	·831	·802	·773	·746	·719	·692	·666	·641	·617	·593
14	·995	·961	·928	·896	·865	·835	·805	·777	·749	·722	·695	·669	·644	·619	·595
15	1·000	·965	·932	·900	·869	·838	·809	·780	·752	·725	·698	·672	·647	·622	·598
16°	1·005	·970	·937	·904	·873	·842	·813	·784	·756	·728	·702	·676	·650	·625	·601
17	1·010	·975	·942	·909	·877	·847	·817	·788	·760	·732	·705	·679	·653	·628	·604
18	1·015	·981	·947	·914	·882	·851	·821	·792	·764	·736	·709	·683	·657	·632	·607
19	1·021	·986	·952	·919	·887	·856	·826	·797	·768	·741	·713	·687	·661	·635	·611
20	1·028	·992	·958	·925	·893	·862	·831	·802	·773	·745	·718	·691	·665	·639	·614
21°	1·034	·999	·964	·931	·899	·867	·837	·807	·778	·750	·722	·696	·669	·644	·618
22	1·042	1·006	·971	·938	·905	·873	·843	·813	·784	·755	·727	·700	·674	·648	·623
23	1·049	1·013	·978	·944	·912	·880	·849	·819	·789	·761	·733	·705	·679	·653	·627
24	1·057	1·021	·986	·952	·919	·886	·855	·825	·795	·766	·738	·711	·684	·658	·632
25	1·066	1·029	·993	·959	·926	·893	·862	·831	·802	·773	·744	·717	·689	·663	·637
26°	1·074	1·038	1·002	·967	·934	·901	·869	·838	·808	·779	·750	·723	·695	·669	·642
27	1·084	1·047	1·011	·976	·942	·909	·877	·846	·815	·786	·757	·729	·701	·674	·648
28	1·094	1·056	1·020	·985	·950	·917	·885	·853	·823	·793	·764	·736	·708	·681	·654
29	1·104	1·066	1·029	·994	·959	·926	·893	·862	·831	·801	·771	·743	·714	·687	·660
30	1·115	1·077	1·040	1·004	·969	·935	·902	·870	·839	·809	·779	·750	·722	·694	·667
31°	1·127	1·088	1·050	1·014	·979	·945	·911	·879	·848	·817	·787	·758	·729	·701	·674
32	1·139	1·100	1·062	1·025	·989	·955	·921	·889	·857	·826	·795	·766	·737	·709	·681
33	1·151	1·112	1·074	1·037	1·001	·966	·932	·899	·866	·835	·804	·774	·745	·716	·688
34	1·165	1·125	1·086	1·049	1·012	·977	·942	·909	·876	·845	·814	·783	·754	·725	·696
35	1·179	1·138	1·099	1·061	1·024	·989	·954	·920	·887	·855	·823	·793	·763	·734	·705
36°	1·194	1·153	1·113	1·074	1·037	1·001	·966	·931	·898	·866	·834	·803	·772	·743	·714
37	1·209	1·168	1·127	1·088	1·051	1·014	·978	·944	·910	·877	·845	·813	·782	·752	·723
38	1·225	1·183	1·143	1·103	1·065	1·028	·991	·956	·922	·889	·856	·824	·793	·763	·733
39	1·243	1·200	1·159	1·119	1·080	1·042	1·005	·970	·935	·901	·868	·836	·804	·773	·743
40	1·261	1·217	1·175	1·135	1·095	1·057	1·020	·984	·948	·914	·881	·848	·816	·784	·754
41°	1·280	1·236	1·193	1·152	1·112	1·073	1·035	·998	·963	·928	·894	·860	·828	·796	·765
42	1·299	1·255	1·212	1·170	1·129	1·090	1·051	1·014	·978	·942	·908	·874	·841	·809	·777
43	1·320	1·275	1·231	1·189	1·147	1·107	1·068	1·030	·993	·957	·922	·888	·854	·822	·789
44	1·342	1·296	1·252	1·208	1·166	1·126	1·086	1·048	1·010	·973	·938	·903	·869	·835	·803
45	1·366	1·319	1·273	1·229	1·187	1·145	1·105	1·066	1·027	·990	·954	·918	·884	·850	·817
46°	1·390	1·342	1·296	1·251	1·208	1·166	1·125	1·085	1·046	1·008	·971	·935	·900	·865	·831
47	1·416	1·367	1·320	1·275	1·230	1·187	1·146	1·105	1·065	1·027	·989	·952	·916	·881	·847
48	1·443	1·394	1·346	1·299	1·254	1·210	1·168	1·126	1·086	1·046	1·008	·971	·934	·898	·863
49	1·472	1·421	1·372	1·325	1·279	1·234	1·191	1·149	1·107	1·067	1·028	·990	·952	·916	·880
50	1·502	1·451	1·401	1·352	1·305	1·260	1·215	1·172	1·130	1·089	1·049	1·010	·972	·935	·898
51°	1·534	1·482	1·431	1·381	1·333	1·287	1·241	1·197	1·154	1·113	1·072	1·032	·993	·955	·917
52	1·569	1·515	1·462	1·412	1·363	1·315	1·269	1·224	1·180	1·137	1·096	1·055	1·015	·976	·938
53	1·605	1·550	1·496	1·444	1·394	1·346	1·298	1·252	1·207	1·163	1·121	1·079	1·038	·998	·959
54	1·643	1·586	1·532	1·479	1·428	1·378	1·329	1·282	1·236	1·191	1·148	1·105	1·063	1·022	·982
55	1·684	1·626	1·570	1·516	1·463	1·412	1·362	1·314	1·267	1·221	1·176	1·132	1·089	1·048	1·007
56°	1·727	1·668	1·610	1·555	1·501	1·448	1·397	1·348	1·299	1·252	1·206	1·161	1·117	1·075	1·032
57	1·773	1·712	1·653	1·596	1·541	1·487	1·435	1·384	1·334	1·286	1·238	1·192	1·147	1·103	1·060
58	1·822	1·760	1·699	1·640	1·583	1·528	1·474	1·422	1·371	1·321	1·273	1·225	1·179	1·134	1·090
59	1·875	1·811	1·748	1·688	1·629	1·572	1·517	1·463	1·411	1·360	1·310	1·261	1·213	1·167	1·121
60	1·931	1·865	1·801	1·739	1·678	1·620	1·563	1·507	1·453	1·400	1·349	1·299	1·250	1·202	1·155

To name Azimuth { In North latitude put **N** for a – 'Error,' and **S** for a + 'Error.'
In South latitude put **S** for a – 'Error,' and **N** for a + 'Error.'

C.

The subjoined quantities shew the error produced in the Longitude by an error of 1′ in the Latitude
They represent the sum or difference of the A and B values.

Lat.	TRUE AZIMUTH.														
	61°	62°	63°	64°	65°	66°	67°	68°	69°	70°	71°	72°	73°	74°	75°
0°	·554	·532	·510	·488	·466	·445	·424	·404	·384	·364	·344	·325	·306	·287	·268
1	·554	·532	·510	·488	·466	·445	·425	·404	·384	·364	·344	·325	·306	·287	·268
2	·555	·532	·510	·488	·467	·446	·425	·404	·384	·364	·345	·325	·306	·287	·268
3	·555	·532	·510	·488	·467	·446	·425	·405	·384	·364	·345	·325	·306	·287	·268
4	·556	·533	·511	·489	·467	·446	·426	·405	·385	·365	·345	·326	·306	·287	·269
5	·556	·534	·511	·490	·468	·447	·426	·406	·385	·365	·346	·326	·307	·288	·269
6°	·557	·535	·512	·490	·469	·448	·427	·406	·386	·366	·346	·327	·307	·288	·269
7	·558	·536	·513	·491	·470	·449	·428	·407	·387	·367	·347	·327	·308	·289	·270
8	·560	·537	·515	·493	·471	·450	·429	·408	·388	·368	·348	·328	·309	·290	·271
9	·561	·538	·516	·494	·472	·451	·430	·409	·389	·369	·349	·329	·310	·290	·271
10	·563	·540	·517	·495	·474	·452	·431	·410	·390	·370	·350	·330	·310	·291	·272
11°	·565	·542	·519	·497	·475	·454	·432	·412	·391	·371	·351	·331	·311	·292	·273
12	·567	·544	·521	·499	·477	·455	·434	·413	·392	·372	·352	·332	·313	·293	·274
13	·569	·546	·523	·501	·479	·457	·436	·415	·394	·374	·353	·333	·314	·294	·275
14	·571	·548	·525	·503	·481	·459	·437	·416	·396	·375	·355	·335	·315	·296	·276
15	·574	·550	·527	·505	·483	·461	·439	·418	·397	·377	·356	·336	·317	·297	·277
16°	·577	·553	·530	·507	·485	·463	·442	·420	·399	·379	·358	·338	·318	·298	·279
17	·580	·556	·533	·510	·488	·466	·444	·422	·401	·381	·360	·340	·320	·300	·280
18	·583	·559	·536	·513	·490	·468	·446	·425	·404	·383	·362	·342	·321	·302	·282
19	·586	·562	·539	·516	·493	·471	·449	·427	·406	·385	·364	·344	·323	·303	·283
20	·590	·566	·542	·519	·496	·474	·452	·430	·408	·387	·366	·346	·325	·305	·285
21°	·594	·570	·546	·522	·499	·477	·455	·433	·411	·390	·369	·348	·327	·307	·287
22	·598	·573	·550	·526	·503	·480	·458	·436	·414	·393	·371	·350	·330	·309	·289
23	·602	·578	·554	·530	·507	·484	·461	·439	·417	·395	·374	·353	·332	·312	·291
24	·607	·582	·558	·534	·510	·487	·465	·442	·420	·398	·377	·356	·335	·314	·293
25	·612	·587	·562	·538	·515	·491	·468	·446	·424	·402	·380	·359	·337	·316	·296
26°	·617	·592	·567	·543	·519	·495	·472	·450	·427	·405	·383	·362	·340	·319	·298
27	·622	·597	·572	·547	·523	·500	·476	·453	·431	·408	·386	·365	·343	·322	·302
28	·628	·602	·577	·552	·528	·504	·481	·458	·435	·412	·390	·368	·346	·325	·303
29	·634	·608	·583	·558	·533	·509	·485	·462	·439	·416	·394	·371	·350	·328	·306
30	·640	·614	·588	·563	·538	·514	·490	·467	·443	·420	·398	·375	·353	·331	·309
31°	·647	·620	·594	·569	·544	·519	·495	·471	·448	·425	·402	·379	·357	·335	·313
32	·654	·627	·601	·575	·550	·525	·501	·476	·453	·429	·406	·383	·361	·338	·316
33	·661	·634	·608	·582	·556	·531	·506	·482	·458	·434	·411	·387	·365	·342	·319
34	·669	·641	·615	·588	·562	·537	·512	·487	·463	·439	·415	·392	·369	·346	·323
35	·677	·649	·622	·595	·569	·544	·518	·493	·469	·444	·420	·397	·373	·350	·327
36°	·685	·657	·630	·603	·576	·550	·525	·499	·474	·450	·426	·402	·378	·354	·331
37	·694	·666	·638	·611	·584	·557	·532	·506	·481	·456	·431	·407	·383	·359	·336
38	·703	·675	·647	·619	·592	·565	·539	·513	·487	·462	·437	·412	·388	·364	·340
39	·713	·684	·656	·628	·600	·573	·546	·520	·494	·468	·443	·418	·393	·369	·345
40	·724	·694	·665	·637	·609	·581	·554	·527	·501	·475	·449	·424	·399	·374	·350
41°	·734	·705	·675	·646	·618	·590	·562	·535	·509	·482	·456	·431	·405	·380	·355
42	·746	·715	·686	·656	·627	·599	·571	·544	·517	·490	·463	·437	·411	·386	·361
43	·758	·727	·697	·667	·638	·609	·580	·552	·525	·498	·471	·444	·418	·392	·366
44	·771	·739	·708	·678	·648	·619	·590	·562	·534	·506	·479	·452	·425	·399	·372
45	·784	·752	·721	·690	·659	·630	·600	·571	·543	·515	·487	·460	·432	·406	·379
46°	·798	·765	·733	·702	·671	·641	·611	·582	·553	·524	·496	·468	·440	·413	·386
47	·813	·780	·747	·715	·684	·653	·622	·592	·563	·534	·505	·476	·448	·420	·393
48	·828	·795	·761	·729	·697	·665	·634	·604	·574	·545	·515	·486	·457	·429	·400
49	·845	·810	·777	·743	·711	·679	·647	·616	·585	·555	·525	·495	·466	·437	·408
50	·862	·827	·793	·759	·725	·693	·660	·629	·597	·566	·536	·505	·476	·446	·417
51°	·881	·845	·810	·775	·741	·707	·674	·642	·610	·578	·547	·516	·486	·456	·426
52	·900	·864	·828	·792	·757	·723	·689	·656	·623	·591	·559	·528	·497	·466	·435
53	·921	·884	·847	·810	·775	·740	·705	·671	·638	·605	·572	·540	·508	·476	·445
54	·943	·905	·867	·830	·793	·757	·722	·687	·653	·619	·586	·553	·520	·488	·456
55	·966	·927	·888	·850	·813	·776	·740	·704	·669	·635	·600	·566	·533	·500	·467
56°	·991	·951	·911	·872	·834	·796	·759	·723	·686	·651	·616	·581	·547	·513	·479
57	1·018	·976	·936	·896	·856	·817	·779	·742	·705	·668	·632	·597	·561	·526	·492
58	1·046	1·003	·962	·920	·880	·840	·801	·762	·724	·687	·650	·613	·577	·541	·506
59	1·076	1·032	·989	·947	·905	·864	·824	·784	·745	·707	·669	·631	·594	·557	·520
60	1·109	1·063	1·019	·975	·933	·890	·849	·808	·768	·728	·689	·650	·611	·573	·536

To name Azimuth { In North latitude put N for a − 'Error,' and S for a + 'Error.'
{ In South latitude put S for a − 'Error,' and N for a + 'Error.'

C.

The subjoined quantities shew the error produced in the Longitude by an error of 1′ in the Latitude.
They represent the sum or difference of the A and B values.

Lat	TRUE AZIMUTH.														
	76°	77°	78°	79°	80°	81°	82°	83°	84°	85°	86°	87°	88°	89°	90°
0°	·249	·231	·213	·194	·176	·158	·141	·123	·105	·087	·070	·052	·035	·017	·000
1	·249	·231	·213	·194	·176	·158	·141	·123	·105	·088	·070	·052	·035	·017	·000
2	·249	·231	·213	·194	·176	·158	·141	·123	·105	·088	·070	·052	·035	·017	·000
3	·250	·231	·213	·195	·177	·159	·141	·123	·105	·088	·070	·052	·035	·017	·000
4	·250	·231	·213	·195	·177	·159	·141	·123	·105	·088	·070	·053	·035	·017	·000
5	·250	·232	·213	·195	·177	·159	·141	·123	·106	·088	·070	·053	·035	·018	·000
6	·251	·232	·214	·195	·177	·159	·141	·123	·106	·088	·070	·053	·035	·018	·000
7	·251	·233	·214	·196	·178	·160	·142	·124	·106	·088	·070	·053	·035	·018	·000
8	·252	·233	·215	·196	·178	·160	·142	·124	·106	·088	·071	·053	·035	·018	·000
9	·252	·234	·215	·197	·179	·160	·142	·124	·106	·089	·071	·053	·035	·018	·000
10	·253	·234	·216	·197	·179	·161	·143	·125	·107	·089	·071	·053	·035	·018	·000
11	·254	·235	·217	·198	·180	·161	·143	·125	·107	·089	·071	·053	·036	·018	·000
12	·255	·236	·217	·199	·180	·162	·144	·126	·107	·089	·071	·054	·036	·018	·000
13	·256	·237	·218	·199	·181	·163	·144	·126	·108	·090	·072	·054	·036	·018	·000
14	·257	·238	·219	·200	·182	·163	·145	·127	·108	·090	·072	·054	·036	·018	·000
15	·258	·239	·220	·201	·183	·164	·145	·127	·109	·091	·072	·054	·036	·018	·000
16	·259	·240	·221	·202	·183	·165	·146	·128	·109	·091	·073	·055	·036	·018	·000
17	·261	·241	·222	·203	·184	·166	·147	·128	·110	·091	·073	·055	·037	·018	·000
18	·262	·243	·223	·204	·185	·167	·148	·129	·111	·092	·074	·055	·037	·018	·000
19	·264	·244	·225	·206	·186	·168	·149	·130	·111	·093	·074	·055	·037	·018	·000
20	·265	·246	·226	·207	·188	·169	·150	·131	·112	·093	·074	·056	·037	·019	·000
21	·267	·247	·228	·208	·189	·170	·151	·132	·113	·094	·075	·056	·037	·019	·000
22	·269	·249	·229	·210	·190	·171	·152	·132	·113	·094	·075	·057	·038	·019	·000
23	·271	·251	·231	·211	·192	·172	·153	·133	·114	·095	·076	·057	·038	·019	·000
24	·273	·253	·233	·213	·193	·173	·154	·134	·115	·096	·077	·057	·038	·019	·000
25	·275	·255	·235	·214	·195	·175	·155	·135	·116	·097	·077	·058	·039	·019	·000
26	·277	·257	·236	·216	·196	·176	·156	·137	·117	·097	·078	·058	·039	·019	·000
27	·280	·259	·239	·218	·198	·178	·158	·138	·118	·098	·078	·059	·039	·020	·000
28	·282	·261	·241	·220	·200	·179	·159	·139	·119	·099	·079	·059	·040	·020	·000
29	·285	·264	·243	·222	·202	·181	·161	·140	·120	·100	·080	·060	·040	·020	·000
30	·288	·267	·245	·224	·204	·183	·162	·142	·121	·101	·081	·061	·040	·020	·000
31	·291	·269	·248	·227	·206	·185	·164	·143	·123	·102	·082	·061	·041	·020	·000
32	·294	·272	·251	·229	·208	·187	·166	·145	·124	·103	·082	·062	·041	·021	·000
33	·297	·275	·253	·232	·210	·189	·168	·146	·125	·104	·083	·062	·042	·021	·000
34	·301	·278	·256	·234	·213	·191	·170	·148	·127	·106	·084	·063	·042	·021	·000
35	·304	·282	·259	·237	·215	·193	·172	·150	·128	·107	·085	·064	·043	·021	·000
36	·308	·285	·263	·240	·218	·196	·174	·152	·130	·108	·086	·065	·043	·022	·000
37	·312	·289	·266	·243	·221	·198	·176	·154	·132	·110	·088	·066	·044	·022	·000
38	·316	·293	·270	·247	·224	·201	·178	·156	·133	·111	·089	·067	·044	·022	·000
39	·321	·297	·274	·250	·227	·204	·181	·158	·135	·113	·090	·067	·045	·022	·000
40	·325	·301	·277	·254	·230	·207	·183	·160	·137	·114	·091	·068	·046	·023	·000
41	·330	·306	·282	·258	·234	·210	·186	·163	·139	·116	·093	·069	·046	·023	·000
42	·336	·311	·286	·262	·237	·213	·189	·165	·141	·118	·094	·071	·047	·023	·000
43	·341	·316	·291	·266	·241	·217	·192	·168	·144	·120	·096	·072	·048	·024	·000
44	·347	·321	·295	·270	·245	·220	·195	·171	·146	·122	·097	·073	·049	·024	·000
45	·353	·326	·301	·275	·249	·224	·199	·174	·149	·124	·099	·074	·049	·025	·000
46	·359	·332	·306	·280	·254	·228	·202	·177	·151	·126	·101	·075	·050	·025	·000
47	·366	·339	·312	·285	·259	·232	·206	·180	·154	·128	·103	·077	·051	·026	·000
48	·373	·345	·318	·290	·264	·237	·210	·183	·157	·131	·105	·078	·052	·026	·000
49	·380	·352	·324	·296	·269	·241	·214	·187	·160	·133	·107	·080	·053	·027	·000
50	·388	·359	·331	·302	·274	·246	·219	·191	·164	·136	·109	·082	·054	·027	·000
51	·396	·367	·338	·309	·280	·252	·223	·195	·167	·139	·111	·083	·055	·028	·000
52	·405	·375	·345	·316	·286	·257	·228	·199	·171	·142	·114	·085	·057	·028	·000
53	·414	·384	·353	·323	·293	·263	·234	·204	·175	·145	·116	·087	·058	·029	·000
54	·424	·393	·362	·331	·300	·269	·239	·209	·179	·149	·119	·089	·059	·030	·000
55	·435	·403	·371	·339	·307	·276	·245	·214	·183	·153	·122	·091	·061	·030	·000
56	·446	·413	·380	·348	·315	·283	·251	·220	·188	·156	·125	·094	·062	·031	·000
57	·458	·424	·390	·357	·324	·291	·258	·225	·193	·161	·128	·096	·064	·032	·000
58	·471	·436	·401	·367	·333	·299	·265	·232	·198	·165	·132	·099	·066	·033	·000
59	·484	·448	·413	·377	·342	·308	·273	·238	·204	·170	·136	·102	·068	·034	·000
60	·499	·462	·425	·389	·353	·317	·281	·246	·210	·175	·140	·105	·070	·035	·000

To name Azimuth { In North latitude put N for a – 'Error,' and S for a + 'Error.'
In South latitude put S for a – 'Error,' and N for a + 'Error.'

CHAPTER X.

LONGITUDE BY CHRONOMETER.

First meridian —the Royal Observatory at Greenwich.

If, in the determination of *latitude, Time* be an element of *importance*, it becomes an absolute *necessity* where *longitude* is concerned—this latter being invariably found afloat by a comparison of the time at ship with the time at some other place which may happen to be chosen as a starting point from which to measure. With us this starting point is the meridian of the transit instrument at the Royal Observatory of Greenwich; and, by international consent, it has recently been arranged that this will in future be considered the *First Meridian* for the entire globe, and foreign charts graduated accordingly.*

Greenwich Observatory was founded in 1675, in the words of the Royal warrant, *to promote the interests of Navigation.* So well has the original intention been kept in view, and so faithfully have successive Astronomers carried out the spirit of the Royal mandate, that if the work of all the other recognised observatories of the world, numbering about 180, were neglected or destroyed, the data in the annual volumes of Greenwich Observatory would be sufficient not only to build anew the science of Navigation, but to reconstruct the entire planetary and lunar theories.

Surely there can be no more flattering commentary on the value of a well-planned system of observatory work, closely followed through two centuries with true Anglo-Saxon pertinacity. Indeed, it may be said that the function of Astronomy in promoting the development of Navigation, and in fostering the extension of Commerce, has been completed.

Longitude—how defined and measured

The *longitude* of a place, by our reckoning, may be defined as

* At the Conference the French representative stood on his dignity and was the only dissenter—on what grounds the writer does not know, as England for many a long day has certainly taken the lead in maritime matters.

an arc of the equator, included between the meridian of Greenwich and the meridian of the particular spot referred to; and is measured either in *space* (° ′ ″), or in *time* (hrs. m. s.). Or, since the meridians all run together to a point at the poles, the longitude of any place on the earth's surface may also be defined as the *angle at the Pole*, included between the meridian of the place and some assumed *First Meridian*, such as Greenwich.

Value in different latitudes.

Owing to this *convergence* of the meridians just alluded to, a degree of longitude has different absolute values, according to the latitude in which it is measured. Thus, a degree of longitude on the equator is equal to 60 nautical or geographical miles. In the latitude of Christiana, in Norway, (60° N.), it is equal to 30 miles; in 83° 20½′ N.—the highest latitude attained by Captain (now Admiral) Markham in the 1876 Arctic Expedition under the late Captain (afterwards Admiral) Sir George Nares—a degree of longitude is only 7 miles; * and at the North Pole itself, in Lat. 90°, longitude has no existence whatever, and the sun always bears true south during the six months of the year that he is visible.

When referring, therefore, to a measure of longitude, it is improper to use the word *miles*. The symbols ° ′ ″ should be spoken of as degrees, *minutes*, and seconds.

As the sun, which is the great timekeeper for the world, returns every 24 hours, or thereabouts, to the same meridian, after describing a complete circle, or 360°,—it follows, by simple division, that *one hour of time* is equal to 15° (degrees) of longitude; *one minute of time* is equal to 15′ (minutes) of longitude; and *one second of time* is equal to 15″ (seconds) of longitude.

Longitude in time, how converted into arc.

As mentioned in a previous chapter, there are several astronomical modes of taking account of time, but that which regulates the business of life is naturally reckoned by the sun, which divides the 24 hours into alternate periods of day and night—light and darkness. It is mid-day, or noon, at a place when the sun is on its *upper* meridian, and midnight when on its *lower* meridian, at which latter time it has accomplished half (180°) its journey round the earth. Owing to the earth revolving left-handed on

* In the spring of 1882, this great feat of courage and endurance was just surpassed by Lieut. Lockwood, who was second in command of the United States Expedition under Lieut. (now General) A. W. Greely, U.S.A., succeeded in planting the "Stars and Stripes" in Lat. 83° 24′ N., and Long. 40° 46′ W. The expedition left New York in the summer of 1881, and was relieved in the summer of 1884, just as Greely and the remnant of his party were on the point of succumbing to cold and starvation. In February of 1882 the thermometer registered minus 63° Faht., or 95° *below freezing*.

On April 8th, 1895, Nansen and Hjalmar Johansen—his sole companion—reached Lat. 86° 13¾′ N. in about Long. 95° E. Thence to the Pole was only 227 miles, but the ice was impassable, and there was nothing for it but to abandon the attempt. Still more recently Prince Luigi Almedeo of Savoy Aosta, Duke of the Abruzzi, in the *Stella Polaris*, reached 86° 33′ N. She left Christiania in June, 1899, and after 11 months in the polar ice she drifted to the then farthest North on record. It was reserved for Civil Engineer (now Admiral) R. E. Peary, U.S.N., to arrive at the North Pole on 6th April, 1909. On 14th December, 1911, Amundsen succeeded in reaching the South Pole; a feat equalled by the late Captain R. F. Scott, R.N., on 17th January, 1912.

its axis, the sun passes the meridian of places to the eastward before it comes to us, so the time at such places must necessarily be in advance of ours; consequently, a citizen of New York, in 74° west longitude, may (about 7 in the morning of *his* time) receive a cablegram from a friend in London telling him of his marriage, which had taken place that same forenoon at 11 o'clock, and of his intention to embark for a honeymoon tour in America. In this case electricity, in conveying the news, had outstripped the sun in the race across the Atlantic—in fact, had beaten him by several hours—since the New Yorker at 7 in the morning (perhaps while still in bed) had intelligence of what had *already* occurred in London at 11 A.M. of the same day.

News by electricity—difference between absolute and relative time

According as to whether his own time is ahead of Greenwich or behind it, the navigator is enabled to decide whether he is in east or west longitude; and one is saved the trouble of even *thinking* over this matter by the well-known rhyme—

Rule for naming longitude east or west.

"Longitude west, Greenwich time best.
Longitude east, Greenwich time least."

As an astronomical question, the determination of longitude resolves itself into the determination of the difference of time *reckoned at the two meridians at the same* ABSOLUTE *instant.* For seamen, the only *really* practical methods of effecting this are—first by the chronometer, and secondly by 'Lunars.' Some navigation books—probably by way of general instruction—make mention of two other methods, namely, Eclipses of Jupiter's satellites, and Occultations of fixed stars, but they are never taken seriously.

Though Jupiter's satellites were not discovered till 1610, one somehow associates the determination of longitude by their means with the Columbian era, when antique caravels found their devious way over the ocean with the aid of the astrolabe, cross-staff, and such-like curios. The method is extremely uncertain, and for use afloat has long been discarded.

Voyages of discovery.

Occultations of *stars* by the moon are little better. No doubt they formed part of the stock-in-trade of our own great navigator, James Cook, who, however, lived to witness the advent of the marine chronometer—an instrument destined to supersede all other methods. Occultations may even have been utilised by the more recent Horsburgh, of East India Directory fame; but those were days—'good old days'—when a degree or so in the reckoning one way or the other was not a matter of much moment, seeing that no one was in a particular hurry, and islands and rocks might be anywhere and everywhere. We have altered all that, and precise surveys permit of the precise navigation now demanded by the exigencies of trade and travel.

It is true occultations of stars *may* still be employed at sea, as the disappearance of a star behind the moon's limb (termed its *immersion*), or its *emersion* on the other side, can be observed with a good ship's telescope—say one with a 2¾-inch aperture and a power of 50—with nearly as great a degree of precision as on shore, always supposing a steady ship—not a quaking steamer—and pleasant conditions of weather and sea; in fact, the gods must be propitious.

Kind of telescope required.

But the moon is small and does not cover much space in her nightly career through the heavens; further, on account of the moon's nearness to the earth causing large parallax, her position relative to the fixed stars varies considerably with the place of the observer; so it happens that an occultation may occur to one observer and not to another almost close by. The moon may just shave the star without occulting it, and occultations skimming the upper or lower limbs are very objectionable. In fact, the occultation of a sufficiently bright star (small ones are snuffed out in untimely fashion by the moon's radiance) is a comparatively rare occurrence, as may be seen by reference to the *Naut. Alm.*, which also gives the limiting parallels of visibility (*vide* pages 412—445 for 1895); but even here it is necessary to point out that the phenomenon is not visible at all the places included between the extreme latitudes thus given, since the true limiting curves do not coincide with the parallels of latitude, but cut the meridians at various angles.

Limits of visibility

Having regard to these drawbacks, and that the subsequent reduction is *considerable*, not one navigator in a thousand would dream of resorting to this mode of checking his chronometers. The 'working' is given in some rather advanced treatises on Nautical Astronomy, and one look at it would be quite enough for most aspirants. An occultation might serve to amuse the 'Honours' gentlemen; there is no harm in trying it.

Neither Eclipses of Jupiter's moons, nor occultations of stars, find a place in the Board of Trade examinations, not even for 'Extra.' They have disappeared also from the new seamen's edition of the *Nautical Almanac*, though for some *occult* reason (no pun intended) the committee of wise men with whom rested the decision as to what should be cut out and what kept in, saw fit to hold on to Eclipses of the sun and moon, as if these inter-

esting phenomena—especially the latter—had the remotest relation to Practical Navigation.

Lunars obsolete

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If the centres of inertia of the moon and earth moved uniformly in circles round the common centre of inertia of the two, the moon, as seen from the earth, would travel through equal angles of a great circle among the stars in equal times; and thus our great lunar astronomical clock would be a perfectly uniform time-keeper.

This supposition is only a rough approximation to the truth; and the moon is, in fact, a very irregular chronometer.

But thanks to the mathematicians, who from the time of Newton have given to what is called the "Lunar Theory" in

Physical Astronomy the perfection which it now possesses, we can tell, for years in advance, where the moon will be relatively to the stars, at any moment of Greenwich Time, more accurately than it can be observed at sea, and almost as accurately as it can be observed in a fixed observatory on shore. Hence the error of the clock is known more exactly than we can read its indications at sea, and the accuracy with which we can find the Greenwich Time by it is practically limited by the accuracy with which we can observe the moon's place relatively to sun, planet, or star. This, unhappily, is very rough in comparison with what is wanted for accurate navigation.

Moon's motion in her orbit. The moon performs her orbital revolution in 27·321 days, and, therefore, moves at an average rate of 0°·55 per hour, or ·55 of a minute of angle per minute of time. Hence to get the Greenwich Time correctly to one minute of time, or longitude within 15′, it is necessary to observe the moon's position accurately to half a minute of angle. This can be done, but it is about the most that can be done in the way of accuracy at sea.

Amount of dependence In the case of Lunars it is done by measuring, with the sextant, the angular distance of the moon from a star, as nearly as may be, in the great circle of the moon's orbital motion. Thus supposing the ship to be navigating in tropical seas, where a minute of longitude is equal to a mile of distance, a careful navigator, with a good sextant, whose errors he has carefully determined, can, by one observation of the lunar distance, find the ship's place within 30 miles of east and west distance. If he has extraordinary skill, and has bestowed extraordinary care on the determination of the errors of his instrument, he may, by repeated observations, attain an accuracy equivalent to the determination of a single lunar distance within a quarter of a minute of angle, and so may find the ship's place within 7 miles of east and west distance; but, *practically*, we cannot expect that a ship's place will be found within less than 20′ of longitude, by the method of lunars, in tropical seas, or within 10′ of longitude in latitude 60°; and to be able to do even so much as this is an accomplishment which not even a good modern navigator, now that the habit of taking lunars is so much lost by the use of chronometers, can be expected to possess.

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Improved lunar theory.

Raper also says,—"Great practice is necessary for measuring the distance successfully; and the application of so many small corrections as are necessary where accuracy is required is, even with extraordinary care and some skill, scarcely compatible with extreme precision."

Lunar discrepancies

Also in a footnote on page 351 of his 19th ed. we find the following:—"The Rev. G. Fisher, in the appendix to Captain Parry's second voyage, states that the mean of 2500 Lunars observed in December differed 14′ from the mean of 2500 observed in March following; and that the mean of the observations made in the same summer differed 10′ from these last, or 24′ from the first." Captain King, in his survey of Australia, notices a discrepancy of a similar kind to the amount of 12′ at the Golbourn Islands.

Lord Kelvin, who is considered one of the most profound mathematicians of our time, referring to this question in his "Lecture on Navigation," says,—"I shall say nothing of Lunars at present, except that they are but seldom used in modern navigation, as their object is to determine Greenwich Time, and this object, except in rare instances, is now-a-days more correctly attained by the use of chronometers than it can be by the astronomical method."

The most Lunar-stricken advocate will scarcely argue that they can be of service in steamers which, go where they may, are never long between ports, and never more than a week or so between intervening capes, islands, rocks, or points of some kind suitable

* Since "Wrinkles" came out in 1881, this last error has practically ceased to exist. Commencing with 1883, the *Naut. Alm.* has employed Newcomb's corrections to Hansen's Tables for the moon, and though the theory of Lunar disturbance is still incomplete, the residual errors are now so very small as not to affect the question from a seaman's point of view. The mean error of the moon's tabular place as predicted in the *N.A.* for 1891 was + $0^s{\cdot}08$ in Right Ascension; + $1''{\cdot}22$ in Longitude (Astr.); and + $0''{\cdot}41$ in Declination. When multiplied by 30 the effect on the Longitude is still too small to be of importance in navigation.

for checking their chronometers. Steamers, therefore, are out of the running, and the utility of Lunars can only be discussed —if discussed at all—in connection with bygone "boxes" making long stretches over the many-wrinkled ocean, whose captains sometimes funked approaching land within a score of miles, no matter how fine the weather. For such men to see it even from the masthead meant "Hands about ship," and nervous apprehension till the yards were full on the other tack. But, as now built and rigged, it must indeed blow hard if a *well-found, well-manned* and *clean-bottomed* ship cannot claw off shore. These items constitute a large order! The sailing ship will soon be but a memory of the past! Old type "Bruisers.

Indifferent charts, and but few of them, may have had something to do with the old desire for "plenty of sea room." It was not uncommon to hear of vessels being taken all round the globe with three or four small-scale general charts. Unless certain of a pilot, such vessels did not *dare* close the shore. If they did, and the anxiously-looked-for pilot failed to turn up promptly, they stood a good chance of being brought up "all standing." But this need not be the case in the twentieth century. Admiralty coast sheets are cheap and good; sailing directions abound; and lighthouses are nearly as numerous as lamps in Piccadilly. There is now absolutely no excuse for vessels bound on over-sea voyages being short of proper navigating gear. Modern navigational facilities.

Just consider any one of the many passages a sailing ship may have to make, and it will be seen that the occasions must be extremely rare when she will not have the chance of 'sighting' something or of 'speaking' other vessels. There *may* be such occasions, and if a prudent master wished to provide against them he would have to fall back on 'Lunars.' But the work of becoming a proficient lunarian cannot be lightly undertaken. It requires, first of all, a really good *Quintant*, firm in its adjustments and perfect in its details. It should have a Kew certificate of Class A. A *Quintant* is specified because the "Distances" often exceed the range of a sextant. It should never be used for anything else, except perhaps sights on shore for chronometer rating. It should be guarded as the apple of its owner's eye; *and the owner himself should practise "Distance" observing until the most difficult positions become fairly easy*—they are never *entirely* so. Sun distances both E. and W. of the moon should be observed, and their mean taken as recommended years ago by Captain Toynbee. This necessitates an interval of a fortnight between sets, and should a spell of rough weather interfere at the critical time, there is nothing for it but patience till the moon is again in position. Lunar requisities

Next come the little niceties of the operation, such as the employment, when possible, of the same screens and the same telescope; the application of the arc errors (when known) and the careful determination of the Index-error both before and after observing; also careful reading-off as instructed in the chapter on the sextant.

Selection of stars and planets.

When stars are observed, those with quickest motion should be selected; the stars' declination should approximate that of the moon. A look at the N.A. (pages xiii—xviii of the month, 1895) will shew by the smallness of the proportional logarithm which bodies best fulfil this condition. If strict attention be paid to these things, and every chance availed of to practise, a man may become proficient *in course of time*, and when this desirable consummation has been arrived at, "lunars" may prove an interesting occupation on long and possibly monotonous voyages.

Lunar records.

It need hardly be said that, as lunars are necessarily spread over long periods, the results should be methodically recorded in a special book and on a definite system. It is important to begin at the very commencement of the voyage, when the chronometers will tell you the error of your lunars; and having a value assigned to them in this manner, they in return will help you to decide as to what your chronometers are doing towards the end of the passage. It goes without saying that the working must be precise, and should be *independently* checked by a second person: this second person should work on his own hook, and the figures of the two computers compared at the finish.

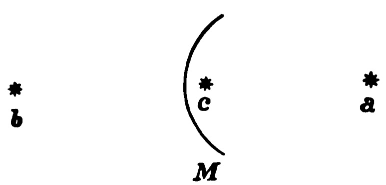
Lunar methods.

Raper devoted nearly 20 pages to Lunars, and one cannot do better than follow the precepts therein laid down. The methods of computation are legion. Krafft's, by natural versed sines, is a good one; so is the late Sir George Airy's. Chauvenet—one of the very best writers on Nautical Astronomy—goes into Lunars very thoroughly. This is a book not so often found in ship libraries as it deserves to be. We will quote him in one place :—" In order to eliminate as far as possible any constant errors of the instrument used in measuring the distance, we should observe distances from stars both east and west of the moon. If the index correction of the sextant is in error, the errors produced in the computed Greenwich time, and consequently in the longitude, will have different signs for the two observations, and will be very nearly equal numerically, they will therefore be nearly eliminated in the mean. If, moreover, the distances are nearly equal, the eccentricity of the sextant* will have nearly the same effect upon each distance, and will therefore be eliminated at the same time with the index-error. Since even the best sextants are liable to an error of eccentricity of as much as 20″, according to the confession of the most skilful makers,† and this error is not readily determined, it is important to eliminate it in this manner whenever practicable. If a circle of reflection is employed which is read off by two opposite verniers, the eccentricity is eliminated from each observation; but even with such an instrument the same method of observation should be followed, in order to eliminate other constant errors."

'Arc errors' of sextant.

"It has been stated by some writers that, by observing distances of *stars* on opposite sides of the moon, we also eliminate a constant error of *observation*, such, for example, as arises from a faulty habit of the observer in making the contact of the moon's limb with the star. This, however, is a mistake; for if the habit of the observer is to make the contact *too close*, that is, to bring the reflected image of the moon's limb somewhat over the star, the effect will be to increase a distance on one side of the moon while it diminishes that on the opposite side, and the effect upon the deduced Greenwich time will be the same in both cases. This will be evident from the following diagram.

Elimination of systematic errors.



"Suppose *a* and *b* are the two stars, *M* the moon's limb. If the observer judges a contact to exist when the star appears within the moon's disc as at *c*, the distance *ac* is too small, and the distance *bc* too great. But, supposing the moon to be moving in the direction from *a* to *b*, each distance will give too early a Greenwich time, for each will give the time when the moon's limb was actually at *c*.

"If, however, we observe the *Sun* in both positions, this kind of error, if really constant, will be eliminated; for, the moon's bright limb being always turned towards the sun, the error will increase both distances, and will produce errors of opposite sign in the Greenwich time. Hence, if a series of lunar distances from the sun has been observed, it will be advisable to form two dis-

Sun-Lunars

* One of the arc errors.—*Lecky*.

† The Kew records shew that this is about the *least* error that can be expected in a first-class instrument. For these, the average may be taken at 40″. The index-error is not an arc error.—*Lecky*.

tinct means,—one, of all the results obtained from *increasing* distances; the other, of all those obtained from *decreasing* distances: the mean of these means will be nearly or quite free from a constant error of observation, and also from constant instrumental errors."

Computing the altitudes.

Of course the altitudes can be computed, but this is hardly to be recommended, as it increases so much the length of the computation. If a couple of reliable officers are at hand, it is much better to *observe* the altitudes in the usual way. An apprentice or the steward can take the chronometer time; but if not, the alts. can be observed both before and after the 'distance,' and subsequently reduced to the time of the latter. This may be done with the aid of Table D.

Cheap Sextants of no use for Lunars.

In the class of vessels most likely to need Lunars (namely, those small craft which, for sake of economy, carry but one chronometer), it is not likely that an expensive Sextant or Quintant will be found; and if by chance it were, it is questionable whether the requisite expertness in observing and calculating would accompany it.

In the ordinary cheap sextants the divisions of the arc are unreliable—sometimes to the extent of 2′—which puts them entirely out of the question for Lunars. In poor instruments, also, the cutting of the vernier and arc at any given angle will often not coincide exactly, and judgment may assign the wrong reading.

Once upon a time Lunars used to be the crucial test of a good navigator. But that was in the "palmy days" of 10% "primage," and freights at from £20 to £40 per ton for the more costly kinds of merchandise, when ships were made snug for the night, and the East India "Tea-wagons" took a couple of years to make the round voyage. Lunars and primage are no more!

Stubborn facts.

The writer of these pages, during a long experience at sea in all manner of vessels, from a collier to a first-class Royal Mail steamer, has not fallen in with a dozen men who had themselves taken Lunars, or had even seen them taken. Whether Lunars are worth cultivating is not deserving of consideration. They are, in fact, as dead as Julius Cæsar; and, without in the least being endowed with the mantle of prophecy, it is correct to say that they will never be resurrectionised, for the best of all reasons—they are no longer required.

Tempora mutantur, et nos mutamur in illis. Steam is superseding sail, and voyages generally are performed in much less time than formerly. Now-a-days, also, as the longitude of most places on the globe has been correctly determined, and radio-telegraphy is to the fore, there are infinitely greater opportunities for rating chronometers.

A new use for Lunars.

If, however, 'Lunars' are of little service to the average navigator, the recent discovery of Dr. H. Schlichter has enhanced their value for the determination of secondary meridians, and the checking, by an independent method, of those already determined by telegraphic time comparisons. Some allusion to these latter will be made presently. Dr. Schlichter's method invokes the aid of photography—so much used of late in astronomical research. By obtaining a parallel series of photographs of the moon and a fixed star or planet on one plate, and afterwards measuring their distances on the plate by a micrometer, he claims to be able to fix the Longitude to within 6", or less than half a second of time. The method combines accuracy with simplicity, and when developed will no doubt be extensively used in the future by surveyors and explorers.

Here we finish with Lunars. *Requiescant in pace.* They have had their day.*

Thanks to the persevering research of the late Mr. Hartnup, (the first astronomer at Bidston), who experimented for this purpose with over 3000 chronometers, the fluctuations of rate due to temperature are fully understood, and rendered capable of easy application. It may, therefore, be confidently stated that there is now no reason why (on board steamers, at least) the correct Greenwich Time should not always be known within eight or ten seconds *at the very outside.*

Correct Greenwich time now easily obtained.

Differences of longitude, how determined on *shore*.

On shore, differences of longitude can be determined with marvellous accuracy by means of the electric telegraph, used in connection with the Transit instrument, Astronomical clock, and Electro-chronograph. This last-mentioned instrument may be regarded as an appendage of the clock, and is a contrivance for visibly recording on a sheet of paper each successive beat of the clock. This is very simply and readily accomplished by electricity. By merely pressing a button, the instant of the occurrence of any celestial phenomenon is *also* registered on the same slip, in such a manner that it can be referred to the preceding clock-beat with great precision. In fact, the interval between two successive beats of the clock can be *easily* divided by scale, so as to

Instruments used.

* The reader will please excuse the Latin. Being a 'dead' language, it is peculiarly suitable for funeral orations. *See* Appendix O.

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Once upon a time Lunars used to be the crucial test of a good navigator. But that was in the "palmy days" of 10% "primage," and freights at from £20 to £40 per ton for the more costly kinds of merchandise, when ships were made snug for the night, and the East India "Tea-wagons" took a couple of years to make the round voyage. Lunars and primage are no more!

Stubborn facts.

The writer of these pages, during a long experience at sea in all manner of vessels, from a collier to a first-class Royal Mail steamer, has not fallen in with a dozen men who had themselves taken Lunars, or had even seen them taken. Whether Lunars are worth cultivating is not deserving of consideration. They are, in fact, as dead as Julius Cæsar; and, without in the least being endowed with the mantle of prophecy, it is correct to say that they will never be resurrectionised, for the best of all reasons—they are no longer required.

Tempora mutantur, et nos mutamur in illis. Steam is superseding sail, and voyages generally are performed in much less time than formerly. Now-a-days, also, as the longitude of most places on the globe has been correctly determined, and radio-telegraphy is to the fore, there are infinitely greater opportunities for rating chronometers.

If, however, 'Lunars' are of little service to the average navigator, the recent discovery of Dr. H. Schlichter has enhanced their value for the determination of secondary meridians, and the checking, by an independent method, of those already determined by telegraphic time comparisons. Some allusion to these latter will be made presently. Dr. Schlichter's method invokes the aid of photography—so much used of late in astronomical research. By obtaining a parallel series of photographs of the moon and a fixed star or planet on one plate, and afterwards measuring their distances on the plate by a micrometer, he claims to be able to fix the Longitude to within 6″, or less than half a second of time. The method combines accuracy with simplicity, and when developed will no doubt be extensively used in the future by surveyors and explorers.

A new use for Lunars.

Here we finish with Lunars. *Requiescant in pace.* They have had their day.*

Thanks to the persevering research of the late Mr. Hartnup, (the first astronomer at Bidston), who experimented for this purpose with over 3000 chronometers, the fluctuations of rate due to temperature are fully understood, and rendered capable of easy application. It may, therefore, be confidently stated that there is now no reason why (on board steamers, at least) the correct Greenwich Time should not always be known within eight or ten seconds *at the very outside.*

Correct Greenwich time now easily obtained.

On shore, differences of longitude can be determined with marvellous accuracy by means of the electric telegraph, used in connection with the Transit instrument, Astronomical clock, and Electro-chronograph. This last-mentioned instrument may be regarded as an appendage of the clock, and is a contrivance for visibly recording on a sheet of paper each successive beat of the clock. This is very simply and readily accomplished by electricity. By merely pressing a button, the instant of the occurrence of any celestial phenomenon is *also* registered on the same slip, in such a manner that it can be referred to the preceding clock-beat with great precision. In fact, the interval between two successive beats of the clock can be *easily* divided by scale, so as to

Differences of longitude, how determined *on shore.*

Instruments used.

* The reader will please excuse the Latin. Being a 'dead' language, it is peculiarly suitable for funeral orations. *See* Appendix O.

admit of the time of the occurrence being read off to the one-hundredth part of a second. The Chronograph, therefore, by subdividing minute portions of time, performs a similar office for the clock that the Vernier does for the Sextant.

The electro-chronograph.

In a succeeding chapter it will be explained that the exact instant of any occurrence cannot be noted by an observer without more or less of delay or anticipation, according to temperament and physical condition at the moment. Further, this error has to be harmonised with somebody else's error. For example, in observatories it is the practice to find this *Personal Equation* for all the observers with reference to one single observer, and the observations are all reduced by its application, so that finally they are tabulated as if made by only one person. The Chronograph has reduced this source of error to a barely appreciable quantity. It is ascertained by one of the many machines for the purpose.

Actual mode of operation.

In ascertaining differences of longitude, the usual method now employed is to note the time occupied by a certain star in passing from the one meridian to the other. Roughly stated, the mode of carrying out this operation in practice is as follows:—At *each* station there is a properly adjusted Transit instrument, also a Chronograph, and at *one* of the stations an Astronomical clock, the *rate* of which has been carefully ascertained. Further, it is necessary that the stations should be placed in direct telegraphic communication with each other.

When the star agreed upon enters the field of the Transit instrument at the eastern station, the assistant to the observer sets the Chronograph in motion, and, by a preconcerted signal, notice is given to the observer at the western station to do the same. The clock, then, by suitable electric connections, records its beats on *both* Chronographs simultaneously, and the instant of the star's transit is *also* recorded at the proper time, by the observer touching a small spring known as a "signal key." This constitutes the first half of the business. When the star, in due course, arrives at the meridian of the western station, the foregoing signals are there repeated in a precisely similar manner, which completes the operation.

The Chronographic Registers are then consulted, and the interval measured by the clock *(after being corrected for its rate)* is, of course, the difference of longitude between the two stations. The foregoing is but one of several telegraphic methods for determining differences of longitude on shore.

At sea there is no means of exactly noting the transit of a heavenly body, so local time on shipboard is always found from an *altitude* of some celestial object, observed with the Sextant, and measured from the Sea horizon. The computation of the hour angle or meridian distance is then made, and the resulting local or ship time is compared directly with the Greenwich Time given by the chronometer at the instant of the observation. Next to the meridian altitude, this problem is about the most familiar to the navigator, and yet experience proves that it is but very imperfectly understood by the majority. *It is quite commonly supposed that the error in the longitude is strictly proportional to the error in the altitude*:—thus, if on a hazy day, the observation is in doubt some 3′ or 4′, it is innocently considered that this also is the limit of error of the longitude. Not so, however, as will presently be shewn; the error in the longitude may *easily* be treble the error in the altitude. (*Vide* Table D).

Differences of longitude, how determined *at sea*.

No direct ratio between errors of observation and errors in the results.

For sights to give the longitude correctly, they must be taken at the right time:—that is, when an error, either in the latitude of the observer or in the altitude observed, will produce the least effect on the hour angle. To fulfil this condition, *the body must be observed when it is on the Prime Vertical.* These two last appear big-sounding words, and some people allow themselves to be unnecessarily scared by them, although they are capable of very simple explanation.

Proper time to take sights for longitude.

A celestial body is said to be *on the Prime Vertical* when it bears true east or west; so that it is merely a term used in opposition or contradistinction to the well known expression "*on the Meridian*," which latter refers to an object having a true north or south bearing. *The Prime Vertical, therefore, is at right angles to the Meridian.* To get the *latitude*, seamen are very familiar with *the* "*Meridian altitude*," and for finding the *longitude* they should be on equally good terms (to coin an expression) with the *Prime Vertical altitude.*

Prime Vertical.

When a celestial object is observed "*on the meridian*," the latitude is found without the *time* being known with greater accuracy than is necessary to correct the declination for the Greenwich date. In the same manner, when an object is observed "*on the Prime Vertical*," the longitude can be found without the necessity of the *latitude* being accurately known—indeed, sometimes an error of 30′ or 40′ will not perceptibly affect the result. To carry out the comparison:—when an "ex-meridian" for *latitude* is observed, a knowledge of the correct *time* is necessary; and the

Latitude of but little importance when observation is made on the Prime Vertical.

further the object is *from the Meridian*, the more important such knowledge becomes. Similarly, when, to determine the *longitude*, an object is observed which is "*Ex-Prime Vertical*," it is essential to a correct result that the *latitude* should be accurately known; and the *further* the object is *from the Prime Vertical*, the more important such knowledge becomes.

Good sights for longitude can *at times* be had within 10 or 20 minutes of noon.

Time sights should be taken, therefore, when the body observed bears true east or west, or as near thereto as possible. According to the latitude and declination, this occurs at various hours in the day, and it sometimes happens in the tropics that the most accurate results are to be got from sights taken *within half an hour of noon*. At such times, also, the horizon is free from that fierce glare which so often dazzles the eye, and renders the horizon indistinct when the altitude is low. This latter important advantage is also gained with stars observed during twilight when the horizon as a rule is strongly marked.

When the observer is on the equator, the Prime Vertical becomes identical with the Celestial Equator. In this case, if the declination be 0°, the sun will rise exactly at east, and *continue* on that bearing till the instant of noon, when it will be directly overhead or in the zenith, and have no compass bearing whatever, and its altitude (90°) may be observed *from any point of the horizon*. Immediately that it has passed the meridian, it will bear west, and *continue* to do so till it sets at six o'clock.

A very important distinction.

In sight-taking for Time, it is therefore of the highest importance that the navigator should free his mind as to whether the object is near to, or far from, the meridian. The real question is as to its *Bearing;* or, in other words, he should think more of the *Azimuth* than of the *Hour-Angle*. REMEMBER THIS.

When, as just mentioned, the latitude and declination both happen to be 0°—which, by-the-bye, will seldom happen to any one individual—there is little or no calculation required to find the hour angle or meridian distance. (Don't forget that these two mean the same thing). Take a sight at *any* altitude; correct it, as usual, by Table 38 of Raper; find the zenith distance by subtracting it from 90°; turn this zenith distance into time, and you have at once the hour angle; or the Apparent Time at Ship, if the object be the sun, and the time be afternoon. Of course in the forenoon you will subtract the hour angle from 12 hrs. or 24 hrs. to get A.T.S., according to the way you wish to apply it.

Parallels of latitude encircle the globe in an east and west direction, and to determine which of the parallels we are situated upon, we select celestial objects at right angles to this direction, or as nearly north and south as we can get them.

Meridians pass from pole to pole in a north and south direction; and, following out the above argument, to determine which of the meridians we are situated upon, we select celestial objects at right angles to the direction, or as nearly east and west as possible. A special reason will be given for this in the next chapter; meanwhile, the reader will kindly accept the statement as reliable. **Meridians.**

It is *very* important that attention should be paid to this point in observing for time, as neglect of it may entail serious disaster.

In the majority of epitomes *there is a table which shews the hour angle of a celestial object when it is on the Prime Vertical*, and daily reference should be made to it, so as to get sights at the most favourable moment. In Raper the table is numbered 29. It also gives the true *altitude* of the body when it is on the Prime Vertical, so that either may be used at pleasure. Of course if the time at ship be not known within a handful of minutes, it will be preferable to use the *altitude*. The sextant can be set to it, *after correcting it backwards, by subtracting the quantity in Table* 38, and all possibility of mistake thus avoided. **Table shewing by inspection the Hour Angle and Alt. of a body when on the Prime Vertical.**

The nearer the bearing is to east or west the better, but in practice it may be a little on either side of it without signifying greatly; and, indeed, clouds and other causes will often interfere to prevent the sight being taken *exactly* at the instant of passing the Prime Vertical. Sailors think nothing of waiting for the *Meridian* altitude to get the latitude: Why not wait for the *Prime Vertical* altitude to get the longitude? The one thing is as reasonable as the other.

The reader is strongly counselled to look over the explanation to the table above specified: it is given on page 411 of Raper's 19th ed.

Another mode of ascertaining the time that a celestial object will bear east or west, is by reference to Burdwood's or Davis's Azimuth Tables, where, by opening at the latitude of the observer (*same* name as declination), and running down the proper column, the required *hour-angle* will be found in the *right-hand* margin, opposite the bearing of 90°. As these tables do not extend beyond 23° of declination, they can only be used with a body whose declination does not exceed that amount. In Raper, the limit for declination is 48°, and for latitude 70°.

Blackburne points out that with latitude and Declin. of *same* name, when the numbers corresponding to the hour-angles in

Tables A and B nearly agree, the time is a good one. For instance, in Latitude 46° N., at hour-angle 0h. 20m. with * *Capella*, the numbers in A and B agree exactly, both being 11′·84 (*vide* p. 431). Therefore, though only 20m. from its meridian passage, *Capella* in that Latitude was exactly on the Prime Vertical, and would give excellent time results.

P. V. observations only possible when Lat. and Declin. have *same* name.

A celestial object *can* only bear true east or west when its declination is of the *same* name as the latitude, *and less in amount*. When the declination is of the same name, but *greater* than the latitude, the object will not pass the Prime Vertical, *but its nearest approach thereto* will be when its diurnal circle coincides with an azimuth circle, or, to express it somewhat differently, the Circle of Altitude and the body's Diurnal Circle will be tangential at the position of maximum azimuth.* This will be rendered clearer by supposing a case, and referring it to the tables of Goodwin or Davis.

Elongation.

For example :—In latitude 10° N., the sun's declination being 23° N., when will it be at its nearest approach to the Prime Vertical, and what will be its bearing in the forenoon at that moment? Open Davis at page 81, and it will be found that, with the data given, the sun will rise bearing N. 66° 37′ E.; its bearing will gradually get *more easterly* till 7·38 A.M., when it will be N. 69° 11′ E., and at its nearest approach to the east and west points; after which it will become *more northerly*, till it arrives on the meridian at noon. In this case, therefore, half-past seven in the morning, or half-past four in the afternoon, will be the best time to take sights for longitude; for though the sun will not be on the Prime Vertical, and therefore not in the most favourable position for giving the time, it is the best that can be got under the circumstances. With the conditions thus cited, an error of 1′ *in the latitude* will only cause an error in the hour angle of a second and a half; and an error of 1′ *in the altitude* will only cause an error of rather more than four seconds and a quarter.

Lat. and Declin. having *contrary* names—best time to observe

As before stated, when the object is *exactly* on the Prime Vertical, an error in the latitude of even 30′ or 40′ will not appreciably affect the result. This knowledge is of incalculable value, as it shows the navigator how the longitude may be obtained when the latitude by account is possibly very much in error. The correct time, thus acquired, may be afterwards used to get the latitude by an "Ex-meridian," when the conditions of

* By regarding Lat. as Declin., and Declin. as Lat., Table 29 of Raper will show the Hour-angle and Alt. of a body at its nearest approach to the Prime Vertical, or greatest elongation. In the example the Alt. is 26° 23′ 10″·1. For formulæ see foot of page 133.

the "Ex-meridian" might unavoidably be such, that without the *correct* time the result deduced might be considerably in error.

When the latitude and declination are of *contrary* names, the object *cannot* bear east or west, but will be nearest to these points at rising and setting—consequently, in such a case, the least unfavourable time for observing will be when the object is near the horizon, but not at a less altitude than 5° or 6°, unless, from the state of the atmosphere, and the relative temperatures of the air and sea, one is led to believe that there is not an unusual amount of refraction.

How to detect excessive refraction.

This can in general be guessed pretty nearly, by noticing the shape of the sun at rising or setting. If it appears flattened, or if its limbs spread out on touching the horizon, or cling to it on leaving, you may be sure there is excessive refraction. On the other hand, if the sun retains its circular shape, and the contact of the limbs is well defined, there is but little refraction. In this latter case, however, it may be *less* than the tabular value, which of course would introduce an error on the *other* side; so that, as a rule, even though the mean refraction be corrected for the height of the barometer and thermometer, observations very near the horizon should be avoided. The careful reader will see from the foregoing, *that the determination of the longitude by the sun in high latitudes during the winter, must be very unsatisfactory.*

During winter, sun unsuitable for determination of longitude.

If a low altitude be used, it is open to errors of refraction; but in winter one seldom gets the chance of *any* altitude till the sun has strength to break through the clouds, at which time its bearing is so far from the Prime Vertical, that any error either in the altitude or latitude will produce a very large one in the longitude. On this account, for four or five months in the year, navigation in our own latitudes is a much less ticklish affair when the stars are brought into action. In most cases they can be selected on, or nearly on, the Prime Vertical, during twilight, and will then give a *very* reliable longitude. It has already been demonstrated that there is no difficulty in getting a good latitude by Meridian or Ex-meridian altitudes of these friendly guides.

Stars suitable at all seasons.

Even supposing that inexpertness in taking stars may cause some error at first, the chances are that it will be less (if the objects selected be well-conditioned) than the inherent error arising from an ill-conditioned observation of the sun, which is concealed, and beyond the observer's control.

Table C (pages 446-451) gives the error of longitude due to an error of 1′ in the *Latitude* for each degree of bearing, from 1°

Tables C and D.

up to 90°. This is a most valuable table, shewing at a glance what to expect from an incorrect latitude. Table D (pages 546-551), in a similar manner to C, gives the error in the longitude due to an error of 1′ in the *Altitude*. Of course an error in the Polar Distance (the third element in the problem for finding the Time) should never occur, and, accordingly, is not taken into consideration.

To avoid confusing Table C with Table D, the latter is printed on green paper. The first and last pages of C are printed in red by way of enjoining caution when using the Table in connection with A. C. Johnson's *Double Chronometer* problem. The reason of the necessity for caution will be explained when this very useful problem comes under consideration.

Reference to either of these Tables will shew that in high latitudes, when the azimuth is small, the error in the longitude may easily be very large—conceive, then, the difficulties of polar navigation at certain seasons. Even in the very ordinary case given on pages 368-369, where the morning sights were taken at 10h. 15m., when the sun had a bearing of S. 23½° E., an error in the *altitude* of only 2′ (nothing very uncommon with a poor horizon or a poor sextant) would falsify the longitude to the extent of 9′. Should this by chance conspire with the error caused by working with the wrong *Latitude*, the total error in the longitude of the ship, *from both causes acting in concert*, would in this particular instance amount to 33′. This will explain some of the bad land-falls made in winter, which at the time were wrongly imputed to the chronometer, or perhaps to an extraordinary "set."

Explanation of bad land-falls.

The quantities in these two tables, it will be seen, depend upon the latitude of the observer and the bearing of the object. The latter is easily arrived at by the Azimuth Tables, or, if great accuracy be a matter of no moment, by a compass bearing corrected for Variation and Deviation.

The Azimuth, as already explained (*vide* pages 133 and 424), can also be got from the combined use of the A B C Tables.

Folly of working to seconds of arc.

In working out sights at sea, it is perfect folly to work to seconds of arc; the nearest quarter of a minute (15″) is quite close enough, and in this Raper helps materially by his Table 68, *where the log. sines, &c., are given for every half minute* (30″) *of arc.* Raper deserves the thanks of seamen for many things, and this is not one of the least of them.

The editor of the present edition of *Norie* has taken the hint, and, not to be behind in this respect, has now printed Table

xxv. to every half minute of arc; but No. 32 of *Inman's Nautical Tables* outdoes them both by giving the logs. to every *quarter* of a minute of arc!!

Nor is it usually necessary to take out the logarithms to more than five figures, any greater exactness being incompatible with the comparatively rude nature of the observation, and in consequence thrown away. **Number of figures in logs.**

To obtain the hour-angle to the nearest second of time, when less than 2 hrs., it is sufficient to take out the logs. to four figures; with hour-angles ranging between 2 hrs. and 5 hrs. (the most common case), five figures will suffice; but when the hour-angle exceeds 5 hrs. six figures are requisite. The reason for this will be found by an examination of the logarithms themselves. It will be seen that their differences are much greater for small hour-angles than for large: the logarithms increase with the increase in the hour-angles, but the *rate* of increase continually diminishes. For example, the difference between the logs. of 1h. 0m. 0s. and 1h. 0m. 1s. is 240, but the difference between the logs. of 6 hrs. 0m. 0s. and 6 hrs. 0m. 1s. is only 32,—using six figure logs. in each case.

Throughout this work special reference is made to points such as these in the endeavour to lead the reader to a correct understanding of the true and essential principles of the science of Navigation. They serve as buoys to mark the channel, and to point out the agencies which influence and determine the accuracy of the result obtained from any given problem.

Hour-angle tables.

Table xxxi. of *Norie* once had but 5-figure logs throughout. Since 1900, however, it has been given 6-figure logs for each second from 0 hr. to 12 hrs.

Table 69 of *Raper*, with the exception of the first 44 minutes, has 6-figure logs. It extends to 12 hours, and the logs are for each second. The hour angles are also expressed in arc.

Table 34 of *Inman* is rather like *Raper's*, but not quite so extensive; it is comprised in 59 pages, and has 6-figure logs. throughout. Beginning with 9 hrs. the logs. are given at 4-second intervals up to 12 hrs.; this is because the values between these points change very slowly. On the whole, therefore, Raper's table is preferable, as the log. of any number of hours, minutes, and seconds can be taken out absolutely at sight.

Usually, the Equation of Time is applied to the Apparent Time

Equation of Time—*when* to apply it.

at Ship to reduce it to Mean Time, but you can steal a little march by applying it to the Greenwich Mean Time *at the commencement* of the work. There is then so much less to do when the calculation is completed at noon. When applied to Greenwich Mean Time in this manner, the equation must be added or subtracted as directed on page II. of the N.A.

Delusive "short methods."

About as good a way as any for finding the time at ship is Raper's or Norie's, there is no difference; it will accordingly be here used in the examples. It is necessary to beware of these so-called "short methods" which appear from time to time. They generally only *look* short, because good care is taken to apply the various corrections *beforehand*, and the unsuspecting reader is deceived by this device. It is seldom, however, that there is a *real* difference of half-a-dozen figures, and the mathematical correctness of the problem is sometimes more than doubtful.

Erroneous short method.

As a case in point we will take a small but expensive pamphlet which contained rules and tables for finding the longitude by chronometer.

When this so-called "short method" is properly overhauled and compared with Raper, we get the following startling result:—"Short method," 56 figures and 5 logarithms, against Raper's 59 figures and 5 logarithms, required to produce the same result. So that by the first method we have the enormous (!!!) gain of *three figures*. Furthermore, that pamphlet contained several glaring errors which makes one rather dubious about the general correctness of the tables, although (for all the writer knows to the contrary) the mathematical principle of the method may be correct enough.

Unless the writer is mistaken, the original pamphlet, to which the above more particularly applies, first appeared at least thirty years ago, but a revised edition was brought out in 1887. It would seem that this was not much better than the original production, as it was most unfavourably reviewed in the April number of the *Naut. Magazine* for 1891.

Hallucinations

Another pamphlet came out some years ago wherein it was stated that chronometers were quite unnecessary to find the longitude at sea, and that it could be done equally well by the method set forth in the pamphlet. But, some way or other, its author has not as yet succeeded in converting the public to his views, and the chronometer trade is more brisk than ever.

To illustrate what has been said relative to the great advantage of taking observations on the Prime Vertical, when desirous of finding the longitude, a few examples will now be given.

Example shewing advantage of observations on Prime Vertical.

EXAMPLE. ⊙ bearing N. 89° 53′ W. (true).

On board the s.s. *British Crown*, about 4 P.M., June 25th, 1880, a chronometer (which was 4m. 0s. slow of G.M.T.) shewed 7h. 43m. 57s. same date, when the alt. of the ⊙ was 37° 49¾′. Eye 32 feet. No index error. Lat. 40° 0′ N., Long. 57° 12′ W., both by dead reckoning. Required the longitude.

```
                                 H. M. S.          °  ′                        S.
Time by chronometer  - -  7 43 57       ⊙  37 49¾               0·52 hourly diff.
Slow  - - - - - - - - -   + 4 00           +  9  Table 38      7.8 G.M.T.
                          -------          -------             ----
G.M.T. - - - - - - - - -  7 47 57     —⊙—37 58¾                 416
Equation of Time - - - -  — 2 30                                364
                          -------                              ----
                          H. M. S.                           + 4·056
Greenwich Apparent Time   7 45 27                            2 25·760
                          =======                            --------
                                                              M.  S.
                                 Corrected Equation of Time - 2 29·82
                                                             ========
                      4·6″ hourly difference of declination.
                      7·8 G.M.T.
                      ---
                      368
                     322
                    -----
                    — 35·88
                 23 23 14·40 declin. at G.M. noon.
                 -----------
                  °  ′  ″
                 23 22 39 corrected declin.
                 90
                 -----
                  °  ′
Polar distance - -  66 37⅓      Cosecant - 0·03720
Latitude - - - -    40 00       Secant -  - 0·11576
Altitude - - - -    37 58¾      Cosine -  - 9·48292
                    ------      Sine   -  - 9·75114
                   144 36                 --------  H. M. S.
                    ------               9·38701 = 3 56 42 Apparent Time at Ship.
½ sum - - - - - -   72 18                ========  7 45 27   ,,      ,,  Greenwich
Remainder - - -     34 19¼                         -------
                    ======     Longitude in time - 3 48 45 = 57° 11¼′ W.
                                                   =======
```

Same sight worked with latitude 39° 20′ N., or 40′ in error.

```
P.D.   66° 37⅓′        0·03720
Lat.   39  20          0·11156
Alt.   37  58¾         9·49076
       ---------       9·74742
       143 56          -------    H.  M.  S.
       ---------       9·38694 =  3   56  41   App. Time at Ship.
½ sum  71  58                     7   45  27    ,,   ,,    Greenwich
Rem.   33  59¼                    ----------
                                  3   48  46 = 57° 11¼′ West.
                                  ==========
```

In this case, with the sun on the Prime Vertical, an error in the latitude of 40′ caused an error in the longitude of only ¼′.

Venus or Jupiter for latitude, simultaneous with sun for longitude.

Venus and Jupiter are often on or near the meridian, when sights of the sun are taken in the morning or afternoon; and, therefore, the latitude found by them serves to work the sights, *and is free from the errors of the run.* This is so manifest an advantage, that the N.A., or the officer of the watch, should occasionally be consulted, to see if either of these planets are available. Their Right Ascensions should differ from that of the sun by *at* *least* two hours, otherwise they will be rendered invisible, by being in the very bright part of the sky surrounding the latter.

Venus, being an "inferior" planet, can never get further away from the sun than three hours and a few minutes; this is termed the planet's elongation.

Mode of observing planets in daylight.

The proper plan is to set the sextant to the *computed* meridian altitude. Use either the direct or inverting telescope (whichever you are most accustomed to), but the last, as it has more power, is to be preferred. *Screw it close down to the plane of the instrument,* and having directed the sight to the north or south point of the horizon, the planet ought to be seen *in the silvered part of the glass.* Of course that part of the sky must be *entirely* free from even the most filmy clouds, and unless the sextant glasses are perfectly clean, and the silvering of the mirrors in good order, there is little use in attempting this observation.

About 1·45 P.M. June 15th, 1882, on board the s.s. "*British Prince,*" homeward bound from Philadelphia, in Latitude 48° 33½′ N., Longitude 24° 30′ W., both by account; Barom. 30″·22; Therm. in the shade on deck 63°; wind S.S.W., light breeze, with smooth water, fine clear weather. Having found by reference to the N.A. (page 237) that Venus (♀) would pass the meridian at 2·7 P.M., decided to observe it, and accordingly set the sextant to the computed altitude 64° 38′ (see rule, page 374).

On looking for the planet near the appointed time, it was seen beautifully distinct a little below the horizon, and no difficulty was experienced in getting the exact meridian altitude, notwithstanding that the midsummer sun was shining *brilliantly* in a cloudless sky, and the fact that there were but two hours difference of Right Ascension between him and Venus.

	H. M.
Mean Time at ship June 15th	2 7
Longitude in Time	1 38
Mean Time at Greenwich ..	3 45
	° ′ ″
Declin. of Venus June 15th	23 8 39 N.
" " June 16th	22 56 55 N.
Variation in 24 hours	11′ 44″
	60
	704″
G.M.T.	× 3·75
	3520
	4928
	2112
	24)2640″·00(110″ = 1′ 50″
	24
	24
	24

	° ′ ″
Declin. of Venus June 15th ..	23 8 39 N.
Decrease in 3hrs. 45m.	− 1 50
Declin. corrected for G.M.T. ..	23° 6′ 49″ N.
	° ′
Obs. alt. of Venus.	64 38¾
Corr. Table 38 of Raper	− 5
True alt.	64 33¾
	90
Merid. zen. dist.	25 26¼ N.
Corrected declin.	23 6¾ N.
Latitude	48° 33′ N.

Now, the apparent angular diameter of Venus on this occasion was only 12″, and when the reader is informed that at inferior conjunction it amounts to as much as 67″, it will be seen that in the absence of clouds there should be usually no difficulty about picking it out even in strong sunlight.

Here, however, it is necessary to put in a word or two. Venus, as already stated, is an inferior planet, that is to say, its orbit lies between the earth and the sun; it therefore exhibits well marked phases resembling those of our moon, and the best time for an observation such as described above, is when the planet is about five weeks from inferior conjunction, or its nearest approach to the earth. Its apparent diameter is then about 40″, and the breadth of the illuminated part nearly 10″, so that rather less than ¼ of the entire disc is illuminated; but this small portion transmits more light at such times than do phases of greater extent, because the latter correspond to greater distances of the planet from the earth. **Phases of Venus.**

Year by year in the N.A. the date is given when Venus attains its greatest brilliancy; thus, on page 473 of the N.A. for 1895, under the heading of PHENOMENA, this is shewn to occur on August 13th, and again on October 25th. After sunset, or before sunrise, Venus, at such times, will cast a distinct shadow.

To find the *latitude*, it has been said that slow-moving stars near the Poles are best; but to find the *longitude*, select bodies on the Prime Vertical, as their motion in altitude is then greatest. It does not signify whether their declination be large or small, since *for any given latitude* the motion in altitude on the Prime Vertical is the same, no matter what the declination.

Again, "Since the change of altitude of any celestial body is greatest at the Equator, and nothing at the Pole, the time deduced by means of altitudes is more correctly determined in low than in high latitudes."* **Observations for longitude best near the Equator.**

In the two following examples of stars taken *near* the Prime Vertical, the formal rule for working them is left out, as the method (with one or two easily noticed exceptions) is so similar to that by the sun. In star observations, the longitude is the difference between the Sidereal Time at Ship, and the Sidereal Time at Greenwich.

Ere this the reader must be pretty familiar with the conversion of Mean Time and Sidereal Time, and should experience no difficulty in mastering what follows. To avoid perplexing him by

* Raper.

anything strikingly different to what is contained in the examples of stars already given, the Epitome method, wherein the sun's Right Ascension is used with the Equation of Time, is not introduced. This adherence to one rule when practicable, is in accordance with the recommendation at foot of page 365.

Examples of stars on the Prime Vertical.

On board the s.s. "*British Crown,*" about 8·30 P.M. June 22nd, 1880, the following observations were made to determine ship's position.

	H. M. S.						
Chron.	11 16 50	obs. alt.	✱ Altair	14° 43½′	bearing S. 88° E. true.	Eye 32 feet	
„	11 24 21	„ „	✱ Polaris	42 15	„ N. 1 E.	„	„ „
„	11 30 49	„ „	✱ Regulus	22 18½	„ S. 86¾ W.	„	„ „

Position by account, Lat. 43° 20′ N. Longitude 43° 24′ W. No index error. Chron. slow of G.M.T. 4m. 0s. Ship making S. 58° W. (true) 11 knots. Polaris, when worked out, gives the latitude as 43° 23¾′ N.

EXAMPLE I. ✱ ALTAIR.

	H. M. S.
Time by chronometer	11 16 50
Slow	+ 4 00
G.M.T.	11 20 50
Sidereal time at G.M. noon	6 4 11
Acceleration for 11h. 21m.	+ 1 52
	H. M. S.
Sidereal time at Greenwich	17 26 53

	° ′
✱'s observed altitude	14 43½
Table 38 of *Raper*	− 8¼
✱'s true altitude..	14 35¼

	° ′		
	90		
✱'s Declination	8 33¼ N.		
✱'s Polar distance	81 26¾	....Cosecant	0·00486
Ship's latitude	43 24½	....Secant	0·13878
✱'s altitude	14 35¼	Cosine	9·53982
		Sine	9·91407
	139 26½		9·59753
Half sum	69 43¼		
Remainder	55 08		

	H. M. S.
✱'s Hour angle	5 11 54 E. = true azimuth S. 88° E. by Burdwood
✱'s Right Ascension	19 44 59 page 358, N.A.
Sidereal Time at Ship	14 33 05
Sidereal Time at Greenwich ..	17 26 53
	H. M. S.
Longitude in time	2 53 48 = 43° 27′ W.

SAME SIGHT WORKED WITH LATITUDE 40′ IN ERROR.

° ′	
81 26¾	0·00486
44 04½	0·14362
14 35¼	9·53292
	9·91582
140 6½	
	9·59722
70 3¼	
55 28	H. M. S.
	5 11 46 E.

Here, notwithstanding that Altair is 2° from the Prime Vertical, the large error of 40′ in the latitude only produces a difference of 8s. in the hour-angle, or 2′ in the longitude.

It will be noticed that the main feature wherein this example differs from the sun is, that the *Sidereal Time at Greenwich* is compared with *the Sidereal Time at Ship*. The Declination and Right Ascension are taken out direct from the N.A. *without the necessity for the smallest correction*—another advantage over the sun. When the hour-angle is east, *subtract* it from the ✱'s Right Ascension, which will give the Right Ascension of the Meridian, or, in other words, the Sidereal Time at Ship.

Declinations of stars require no correction for G.M.T.

Example II.— ✱ Regulus.

	H. M. S.
Time by chronometer	11 30 49
Slow	+ 4 00
G.M.T.	11 34 49
Sidereal time at G.M. noon	6 4 11
Acceleration for 11h. 35m.	+ 1 54
Sidereal Time at Greenwich . ..	17 40 54

	° ′
✱'s obs. alt.	22 18½
Table 38 of *Raper*	− 7¾
✱'s true alt.	22° 10¾

	° ′		
	90		
✱'s Declination	12 33 N.		
✱'s Polar distance	77 27	....Cosecant	0·01050
Ship's latitude	43 23½	....Secant	0·13563
✱'s altitude	22 10¾	Cosine	9·50129
		Sine	9·87994
	143 01		9·53036
Half sum	71 30½		
Remainder	49 19¾		

	H. M. S.	
✱'s Hour-angle	4 44 56	W. = true azimuth, S. 86¼° W. by Burdwood.
✱'s Right Ascension	10 2 1	Page 338, *N.A.*
Sidereal Time at Ship	14 46 57	
Sidereal Time at Greenwich ..	17 40 54	
Longitude in time	2 53 57	= 43° 29¼′ W.
Correction for run between sights		− 3
Longitude corresponding to that by Altair		43° 26¼′ W.

Same Sight worked with Latitude 40′ in Error.

° ′	
77 27	0·01050
44 3½	0·14346
22 10¾	9·49366
	9·88210
143 41	9·52972
71 50½	H. M. S.
49 39¾	4 44 41 W.

The hour-angle being west, is *added* to the ✱'s Right Ascension to procure the Sidereal Time at Ship.

Regulus being further from the Prime Vertical than Altair, the error in the hour-angle is of course greater. Still it is not large, amounting only to 15s., or 3¾′ of longitude for an error of 40′ in the latitude.

The difference in the longitude of the ship as given by Altair and Regulus (the one east and the other west of the meridian) is only ¾′, proving the practicability of getting first-class results from star observations when made at the right time and in the proper manner.

Advice to novices at star work

ADVICE TO BEGINNERS.—Do not despair because your first efforts are unattended with particularly good results. PERSEVERE. "Rome was not built in a day." Practise in *fine* weather, so as to gain confidence, and feel perfectly at home with the work in case of requiring its aid in *bad* weather, or on an emergency. If you do this, you will soon get out of conceit with the sun.

Johnson's method of correcting sights for an error in the latitude worked with

Morning sights, as a rule, are only partially calculated pending the determination at noon of the true latitude, which of course is referred back to the time of observation by the course and distance made in the interval; the late A. C. JOHNSON, in his valuable pamphlet already alluded to, showed how the sights can *at once* be worked out in full with the latitude *by account*, and *afterwards* corrected by Table C. for any error in the latitude worked with. The plan is so simple and convenient that an example is given.

About 9·45 A.M. on board the s.s. "*British Crown*," July 7th. 1880, took following observation for longitude. Eye 28 feet, Chronometer slow of G.M.T., 4m. 3s. Position by account—latitude 39° 51¼′ N., and longitude 53° 1′ W. Ship making east (true) 12 knots.

	H. M. S.		
Chronometer time	1 18 37	Observed altitude .. $\underline{\odot}$	56° 44¾′
Slow	+ 4 3		+ 10
	1 22 40	$-\odot-$	56° 54¾′
Corrected Equation of Time ..	− 4 42		
Greenwich Apparent Time ..	1 17 58		

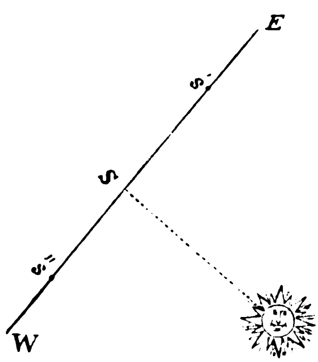
	° ′		
	90		
Corrected declination	22 31¾		
P. D.	67 28¼	Cosecant	0·03447
Latitude by account	39 51¼	Secant	0·11482
Altitude	56 54½	Cosine	9·13722
		Sine	9·62932
	164 14		8·91583
Half sum	82 7		
Remainder ..	25 12¼		

	H. M. S.	
☉'s Hour angle	2 13 26	= true azimuth S. 68° E. nearly, by Burdwood.
Apparent time at Ship .	9 46 34	
Apparent time at Greenwich	13 17 58	
Longitude in time	3 31 24	= 52° 51′ W. at sights.
		− 34½ for run till noon.
Longitude by sight		52° 16½′ W. brought up till noon.
Latitude by account		39° 51½′ N. brought up till noon.

At noon the *true* latitude was found to be 39° 41′ N., or 10¼′ S. of that by account. By Table C, the error of longitude due to an error of 1′ in the latitude is 0′·53, which, multiplied by 10′·2, gives 5½′, to be applied as a correction to the above longitude. We have, therefore, for the true position at noon, latitude 39° 41′ N., longitude 52° 22′ W.

Johnson's rule for applying the correction

Johnson gave a very ingenious, and at the same time simple, method of determining whether the correction is to be added or subtracted.* The plan adopted by the writer, being based upon a graphic representation of the problem, is more instructive, and on that account to be preferred. Here it is. Imagine a line through the ship's position on the chart drawn at right angles to the bearing of the sun, thus:—



Method used by writer for same purpose.

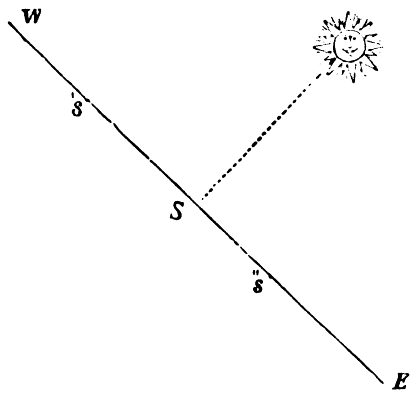
For the reasons *why* the ship may be conceived to be on a line at right angles to the sun's bearing, see next chapter, where the subject is fully explained.

To make the case as plain as possible, let the sun be supposed to bear S.E. Then the line will run N.E. and S.W., as above. Let the point *S.* in the diagram represent the position of the ship as determined by sights worked with the latitude by account. If this turn out to be wrong, and the true latitude be further north, say at *s*′, the diagram shews, when this latitude is pricked off on the line, that the true longitude is more to the eastward. If, however, the true latitude be south of the latitude by account, say at *s*″, then the longitude is thrown to the westward. This

* See pages 507-508.

can easily be done mentally. The plan holds good for a bearing in any quadrant of the compass.

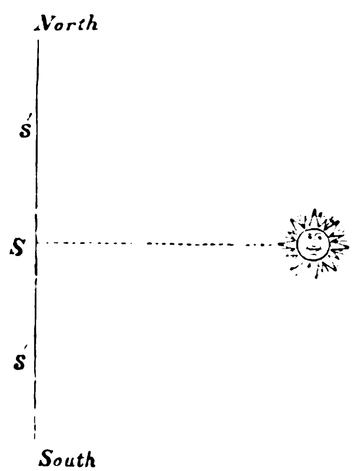
Let us suppose another case, where the celestial object bears N.E. Then the imaginary line would run N.W. and S.E., thus:—



In this case, if the actual latitude be south of the one worked with, as at s'', the longitude will be thrown to the eastward, but if north, it will be thrown to the westward; just the reverse of the preceding example. The reader can test for himself the effect in the other two quadrants.

We will now imagine the sun to bear east, and see what effect is produced on the longitude by an error in the latitude.

Diagram shewing advantage of observations on the Prime Vertical.



Evidently there is no effect at all, as in this case the imaginary line runs north and south. *Hence the advantage of taking sights for longitude when the celestial object is on the Prime Vertical, as a considerable error in the latitude has no effect on the result,* see Table C (page 451), where it is shewn that, with a bearing of 90°, an error in the latitude produces no error in the longitude. There is, however, a limit to this use of an indiscriminate latitude, which will be fully explained in the next chapter. In the meantime, one more illustration.

Let the sun be supposed to bear S. by E. What effect will then be produced on the longitude by an error in the latitude ?

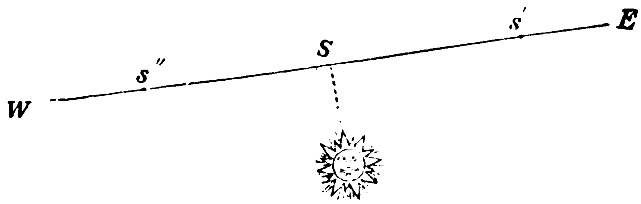


Diagram shewing disadvantage of observs. for time near the Meridian.

It will now be evident that a small error in the latitude will produce a very large one in the longitude; *showing the impropriety of taking sights for Time when the bearing of the object is near the North or South points.* Hence one of the reasons for the red 'danger-signal' on page 446 (Table C). The colouring of the first and last pages of this Table has special reference to the *Double Chronometer* problem, no matter which method may be used.

When applying the correction to the longitude by the mental process, it is always well to imagine the sun or star to have a four-point bearing, such as S.W., N.W., N.E., or S.E., although the *actual* bearing may be quite near to one of the cardinal points. This exaggeration of the case puts more forcibly to the mind the direction in which the correction is to be applied; but until thoroughly proficient, it is certainly advisable to draw the lines roughly on a slip of paper. A little practice, however, will soon do away with the necessity for even this.

It may here be remarked, in parenthesis, that when looking at a chart, for any purpose whatsoever, it should be laid on the table with the north side from you. The mind thus acquires a fixed habit of considering the positions of places with regard to their true bearings from each other. Some men, on the contrary, if sailing south for example, turn the chart with the north side to them, so as more readily (?) to lay off bearings, &c. But this twisting and turning of the chart according to the course steered

Proper way of looking at a chart.

is not to be recommended, and conveys an unstable idea of geographical position.

SHORT EQUAL ALTITUDES (Sun).

Equal altitudes *at sea.*

There is one other mode of finding the longitude by chronometer, which, from its extreme simplicity as usually presented, and the few figures required, is very alluring to people who either suffer from want of energy, or have been insufficiently grounded in first principles. Unfortunately for every one, this 'short cut' mode of treating the problem is only rarely available, and if indiscreetly used, under wrong conditions, will assuredly give wrong results. The problem referred to is that of *Equal Altitudes* taken a few minutes before and after noon. If the course in the interval be nearly east or west, or the vessel be stationary, and the altitude not less than 75°, the method in its simplest form is available, and the longitude will probably not be far from the truth. Sailing ships lying becalmed near the line, or struggling in the 'doldrums,' may find it convenient; but if the course be towards north or south, and the vessel's speed considerable, there will *usually* be a large error due to the observer's change of position (see page 372).

The word 'usually' has been italicised, because it might happen that the ship's latitude and the sun's declination coincided, or nearly so, in which case a north or south course in the interval would not affect the result, seeing that the ship would neither be approaching, nor receding from, the sun. To suit the special conditions detailed above, the following is the

Simple Rule.

Rule for Equal Altitudes at sea.

From 10 to 15 minutes before noon, observe the sun's altitude, and note the time by chronometer. When the sun has fallen to the same altitude P.M. again note the time by *same* chronometer; the mean or half sum of these times, when corrected for the chronometer error, will be the Mean time at Greenwich corresponding to Apparent Noon at Ship. Reduce the Greenwich *Mean* Time to Greenwich *Apparent* Time, by adding or subtracting the Equation, according to the precept at head of page II. of the *Nautical Almanac.* If the longitude be west, the Greenwich Apparent Time turned into arc will be the longitude; but if it be east, subtract the G.A.T. from 12 hours, and *then* turn it into arc.

If another sextant is available for the meridian alt. (let us hope so), it will be just as well to keep this one clamped to the first observation. The shades should also, if possible, remain unchanged.

Example I.

Ship stationary, or steering either East or West (true); or steering in any direction and at any speed with sun near the Prime Vertical.

August 3rd, 1881. Observed equal altitudes ☉ in West Longitude.

	H. M. S.	
Time by chronometer	3 2 10	at A.M. altitude.
Time by chronometer	3 14 20	at P.M. altitude.
	6 16 30	
Middle time	3 8 15	
Chronom. slow of G.M.T.	+ 4 17	
Greenwich Mean Time	3 12 32	
Corrected Equation of Time	— 5 55	Page II., N.A.
	H. M. S.	
Longitude in time	3 6 37	= 46° 39¼′ W. at Noon.

In the foregoing example, the conditions are assumed to be *exceptionally* favourable; but such happy occasions are somewhat of the nature of angel's visits; it is therefore good policy to be prepared for what *ordinarily* happens. There are various approximate modes of eliminating the error due to change of latitude between sights, but, taking all things into consideration, Raper's is about the best. (Pages 288–289, nineteenth ed.). Blackburne is rather a champion of Short Equal Altitudes, and this is the method given in his A and B Tables. It is necessary to know the azimuth, and as Davis's Tables are not available for alts. exceeding 60°, it must be got by some other means: Raper's formula (page 289) is very short; or, failing Raper, the azimuth can, just as quickly, be got from the A B C tables.

Example II.

Where ship has changed her Latitude between sights, and the conditions are less favourable.

August 3rd, 1881.—In east longitude, and about latitude 4° 10′ N., the eye being elevated 22 feet, the altitude of ☉ was observed to be 76° 0′ (rising), when a chronometer which was 10m. 20s. fast of G.M.T. shewed 8h. 30m. 42s. A.M. at Greenwich *same* date. After a lapse of half an hour, during which time the ship had made good N. 33° E. (true) 6 miles, the sun dropped to the same alt., and the time by *same* chronometer was 9h. 2m. 30s. Required the latitude and longitude at noon.

Special Rule.

Take the mean of the A.M. and P.M. times by chronometer. To this apply the error on G.M.T., also the reduced Equation of Time. The result is Greenwich Apparent Time corresponding to noon at Ship; this is on the supposition that the ship has not changed her latitude between sights; otherwise it corresponds to the time of *approximate* noon, and a correction is necessary.

To Find Correction for Change of Latitude.

With half the interval as an hour-angle, find the azimuth as most convenient.

Then;—
To the sine of *half* the difference of latitude made good, add the secant of the latitude, and the co-tangent of the azimuth: the sum, rejecting tens, is the sine of the correction *in time*. (It is sufficient to take out the logs. to three places only).

When the ship has *approached* the sun in the interval, *subtract* the correction from the G.A.T.; when she has *receded* from the sun, *add* it.

With Declin. 17½° N., Latitude 4° 10′ N., and the Hour-Angle 16m., the A B C tables give the Azimuth as 16°. Difference of latitude made between sights = 5′.

Correction for change of position

½ diff. of lat. 2′ 30″	Sine	6·862
Latitude 4° 10′	Secant	10·001
Azimuth 16°	Co-tang.	10·543
Correction – 36s.	Sine	7·406

	H. M. S.	
Time by chron. at A.M. observation ..	8 30 42	☉ 76° 0′
" " P.M. "	9 2 30	
	2)17 33 12	
Middle time by chron.	8 46 36	
Chron. fast of G.M.T.	— 10 20	
Greenwich Mean Time	8 36 16	
Corrected Equation of Time	— 5 56	Page II., N.A.
Greenwich Apparent Time	8 30 20	
Correction for change of latitude	— 36	Note what the omission of this would mean.
	8 29 44	
Noon, or A.T.S. corresponding to middle time by chron.	12 00 00	
	H. M. S.	
Longitude in Time	3 30 16	= 52° 34′ E. at Noon.

Latitude at noon = 4° 12½′ North.

Do not abuse this method by using it at improper times, and be sure that both observations are made with eye at same height above the sea-level.

Better methods usually available.

Now it must be remembered that, in low latitudes where the method of Short Equal Altitudes is possible, it is equally possible to get the App. Time at Ship, from sunrise to within a few minutes of noon, by the ordinary sights if the latitude be known only approximately; for it has been shewn in this chapter that, so long as the sun is near the Prime Vertical, an error, such as is likely to occur in the latitude by dead reckoning, does not signify.

The sun is hardly adapted to the method under consideration. A ship bound south or north soon passes out of range, and whilst within range other methods are available. Reference to Table D will shew that even in moderately high latitudes the change of alt. near noon is very slow. Inversely, an error of only 1′ in the alt. means a large error in the time or longitude.

For these and other reasons the method of "Equal Altitudes at Sea" is not to be recommended when the sun is the body employed. It may, however, be given a place among those auxiliary problems which science places as a reserve, but which should only be resorted to when, without them, the battle would be hopelessly lost.

Short Equal Altitudes of Stars.

These disparaging remarks do not, however, apply where suitable *stars* are concerned. They are to be found spread all over the heavens, and the navigator can take them as he wants them. Substituting stars for the sun, "Short Equal Altitudes" at once rise in value. Blackburne is a strenuous advocate, and by his kind permission the following is taken, nearly *verbatim*, from the text of his A and B Tables. He says:—

"I wish to draw attention here to the value of the Short Equal Altitude problem, especially in the case of stars, because I think it is not sufficiently appreciated by most nautical writers. The problem is more especially useful in the case of stars, owing to there being no appreciable change in a star's declination, and because suitable ones can generally be found in any latitude. Even on dark nights a very fair longitude can generally be obtained, just as when stars for latitude are observed North and South of the meridian. An equally good result is obtained if *both* altitudes are observed the same amount too great, or too small, as if they had both been correct, and the problem is so simple that it takes very little longer than to get the latitude by meridian altitude; I mean, of course, when within the limits where correction for change of latitude or declination is not necessary.

I have several times taken these equal altitudes in my morning watch; sometimes before daylight with an indifferent horizon, and at others with a good horizon a little before sunrise, and they have nearly always agreed splendidly with the star position longitude obtained by double altitude a little before sunrise, when the horizon is perfect.

I do not wish to encourage the abuse of this method by using it beyond its proper limits; and when the *Sun* is observed it will seldom be useful except in the *tropics*, and then principally when running nearly due East or West, as on passages from Penang to Ceylon, Ceylon and Bombay to Aden. When running due East or West *no* correction of altitude or time is required for ship's change of position. Also, when the body observed bears East and West, *no* correction is required for *several* miles change of latitude to the North or South; therefore it follows that when the observed body is near the prime vertical, and the change of latitude is small, it is not practically necessary to make any corrections for change of ship's position.

Best time for equal altitudes.

Table 29 in Raper gives the hour angle and *altitude* of a body on the prime vertical; and most other epitomes also have a table at any rate for giving the hour angle of same (though with limited declination), which is always useful for showing the best time to observe for longitude.

EXAMPLE III.—BY A STAR.

S.S. *Brindisi*, Aden towards Colombo, on 6th Sept., 1885, at 5·25 and 5·35 A.M. (ship time). Observed equal altitudes of ✱ Aldebaran to the Northward at 13h. 49m. 05s. and 13h. 59m. 05s. by chron., which was fast of G.M.T. 37m. 36s. At 5·30 A.M. mer. alt. was observed 83° 13½′, giving lat. 9° 25′ N.

Run in interval S. 75° E. 2′ = D. lat. 0′·5.

In this example, as the star was only 7′ from the meridian, and the ship had receded from the star, 0′ 30″ less altitude was set to sextant for the second observation.

	H. M. S.
1st obs.	13 49 05
2nd obs.	13 59 05
	2)27 48 10
Middle time	13 54 05
Error of chron.	− 37 36
G.M.T. when ✱ passed our meridian	13 16 29

	H. M. S.
Sid. time at preceding G.M. noon on 5th	10 59 01·3
Acceleration for 13h. 16½m., Raper, table 23	+ 2 8·1 + 2·7
Red. sid. time	11 01 12·1
✱'s R.A. + 24h.	28 29 22
M.T. mer. pass. at ship 5th ..	17 28 10
G.M.T. 5th	13 16 29
Long. in time	4 11 41
	= 62° 55′ 15″ E

There is no more work here than with the Sun, as there is no equation of time to apply, and it is easier to reduce the sid. time than to correct the equation.

My usual morning double altitude was taken 3m. before this first sight, by Saturn and Sirius, both East of meridian, the resultant giving longitude 62° 54′ E., which when brought up to the same time is within a mile of the equal altitude longitude. I have taken several with equally good results, though in this case it was probably accidental that so near an agreement with the other observations was obtained, as better results might have been expected with a longer interval of time, when the star was nearer the prime vertical; daylight, however, prevented this.

Choice of stars for equal alts.

It is best to choose stars with declination nearly the same as latitude, or else *of* the *same* name, and the declination less than the latitude; if the declination is greater than the latitude, as in the last example, it does not come to the prime vertical at all, neither does it if the declination and latitude are of contrary names. With latitude and declination of *same* name, when the numbers corresponding to the hour angles in tables A and B nearly agree, is always a good time. For instance, in lat. 46° N., at hour angle 0h. 20m. with ✱ Capella, the numbers in tables A and B exactly agree, both being 11·84, the star, therefore, in that latitude being then exactly on the prime vertical.

The following example will show how a star may sometimes be observed almost on the prime vertical to within 2 or 3 minutes of its meridian passage, or at any time within 2 or 3 hours of its passage.

Example IV.—S.S. '*Brindisi*,' Colombo towards Aden, 13th October, 1885, at 6·24 and 6·36 p.m. (ship time). Observed equal altitudes of ✱ Altair 88° 44′ nearly East and West at 2h. 16m. 55s. and 2h. 28m. 24s. by chronometer, which was fast of G.M.T. 39m. 04s.

The meridian altitude was also observed at 6·30 p.m. 89° 34′ S., giving lat. 8° 46′ N.

Ex. IV.—*By a Star bearing nearly East and West.*

	H. M. S.
1st obs.	2 16 55
2nd obs.	2 28 24
	2)4 45 19
Middle time by chron.	2 22 39·5
Chron. error	− 39 04
G.M.T.	1 43 35·5

	H. M. S.
Sid. time 13th	13 28 50
Acc. for 1h. 43½m.	+ 17
Red. sid. time	13 29 07
✱'s R.A.	19 45 12·5
M.T. mer. pass.	6 16 05·5
G.M.T.	1 43 35·5
Long. in time	4 32 30
	= 68° 7′ 30″ E.

Equal altitudes of this star were taken in daylight for three or four evenings running. Several miles change of ship's position North or South in this case would not have affected the longitude 1′."

Captain Blackburne, now Nautical Adviser to the Marine Department, New Zealand (1906), specially devoted himself to the practical side of navigation, and his opinion in this matter is entitled to very great respect.

To conclude the chapter.—When sight-taking, should an assistant not be available to note the chronometer time, the

A use for the log-glass.

observer himself can very well manage with the aid of a 28s. log-glass. Turn the glass when the altitude is taken, walk to the chronometer and note the time when the sand has run out: from this, subtract the running time of the glass to get the correct instant of observation. *Test the glass.*

CHAPTER XI.

"SUMNER LINES"

This and the following chapter are probably the most important in the book, as explaining and illustrating the geometrical process—underlying the calculation by logarithms which is performed every day by the practical navigator, but of the meaning of which he has very often no conception whatever. He only knows that by certain arithmetical formulæ (learnt off like a parrot) certain results are produced, but *how*, is a mystery. Let us open the pages of this sealed book, by which the navigator may learn to reason for himself, instead of trusting entirely to rules which, when forgotten, leave him adrift on his beam ends.

The *principle* of a problem being understood, one is not dependent on memory for the rules.

In the present chapter it is proposed to shew *to what extent* a single altitude of a heavenly body (say the sun) will reveal the whereabouts of a ship, *the latitude being completely unknown*, and how, when combined with certain *non*-astronomical data, it may be made to give her actual position.

It is of course assumed that the correct Greenwich Time is obtainable by means of chronometers.

We have already seen that a single altitude *on the Meridian* will give the *Latitude* with but trifling calculation; and that a single altitude *on the Prime Vertical* will give the *Longitude*, even though the latitude be but imperfectly known. It remains to shew more particularly *why* this is so, and also, *by using the latitude by dead reckoning*, what information is to be derived from a celestial body which occupies neither the one nor the other of these important positions.

Illustration of "Circle of Equal Altitude."

By way of the simplest illustration, imagine an ordinary flagstaff in a park, and let its base—from the ground to the height of the eye—be painted a different colour from the rest. Let our experimentalist lay off, in any direction from it, a distance of say 100 yards, and having marked the spot by a stake, measure with the sextant the angular altitude of the flagstaff from its truck to the paint-stroke.

Suppose this to be 25°. Now let him go to any number of positions round about the flagstaff, approaching or receding from it, until in every case the same angle (25°) is obtained. At each such spot plant a stake. Connect these various points by some "small-stuff," and if they are sufficiently close together, a circle will be formed, every part of which will be exactly the same distance from the flagstaff in its centre. It is evident that an observer getting an angle of 25° must be *somewhere* on this circle, which accordingly may be termed "*a circle of equal altitude;*" since, if the angle be *greater*, he will be *within* it, and *nearer* to the flagstaff; whilst if the angle be *less*, he will be *outside* of it, and *further* from the flagstaff.

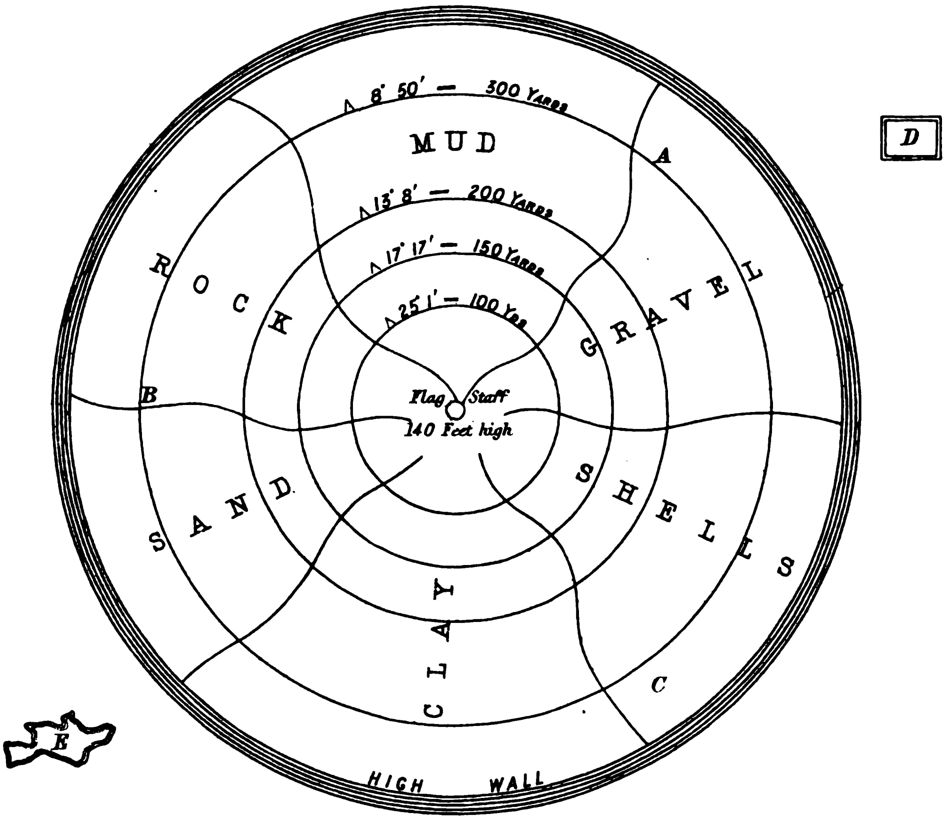
Now, conceive a number of such circles to be described at various distances from the flagstaff. If furnished with a set of tables giving the distance of each from the flagstaff, and its corresponding angle, the observer, on measuring such an angle at any point, will only know that he is *somewhere* on a circle, at a definite distance from the flagstaff. Thus, if the angle obtained were 8° 50′, reference to the tables would merely tell him that he was on a circle every point of which was 300 yards distant from the flagstaff; but if this latter and the circles were enclosed by a very high wall, which shut out from view all external objects, he could not possibly tell his position on that circle with regard to those external objects. He might just as likely be at the point marked *C* in the diagram as at *A* or *B*. If he wished to go to any particular place in the park outside the wall—say to the house at *D*, or to the fish-pond at *E*—he would not know in which direction to shape his course, or by which door to go out.

Circle of Position Illustrated

Let it be supposed, however, that the surface of the ground round about the flagstaff varies very much in character—that in one direction it consists of clay, in another of shells, in another of sand, and so on; and that, in addition to his set of tables, the observer is provided with a plan of the park, shewing the flagstaff and this peculiarity of the ground in its vicinity. So aided, he would at once be able to tell by the *angle* which of the circles he belonged to, and by the *nature of the ground* under his feet what particular part of it he was on, and, consequently, his position relative to the invisible objects outside the wall.

Now this is pretty much what can be done on board ship by substituting the Sun for the truck of the flagstaff, the Horizon for the paint-stroke, the *Epitome* and *Nautical Almanac* for the tables, a Chart for the plan of the park, and Soundings for the surface peculiarities of the ground.

DIAGRAM ILLUSTRATING "CIRCLES OF EQUAL ALTITUDE."



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Next come the various astronomical facts for which the foregoing simile is intended to pave the way.

Circle of Illumination

At any given instant of time the sun is vertically above—or, as it is termed, *in the zenith* of—some point on the earth's surface, and its rays directly illumine that half of the globe nearest to it, the other half being in darkness, more or less complete, according to circumstances. To avoid complications, imagine for the time being the earth to be arrested in its motion, so that the sun remains steady over one particular spot. At this spot an observer with a sextant would find the true altitude of the sun's centre to be 90°, and being therefore exactly overhead, upright objects would throw no shadow. On the other hand, if the observer were situated on any part of the Great Circle* separating the dark from the enlightened half of the globe, the sun would be on his horizon, and its altitude would be 0°. These represent the two *extreme* cases. We have more especially to deal with the first and intermediate ones.

Sub-solar point.

If the Latitude and Longitude of the sun were known,† the Latitude and Longitude of the spot over which it was vertical would also be known, and *vice versâ*. Now, with the *Nautical Almanac* it is very easy to find the sun's position in the heavens at any given moment, and if it were possible to drop a plumb-line from it to the earth's surface, the latitude and longitude of the point of contact would correspond with that of the sun.

Circle of Equal Altitude

If, however, an observer were so situated that, instead of getting 90° as the sun's true altitude, he found it to be only 89°, his position would then be uncertain, since he would only be *somewhere* on the circumference of a "small circle," the centre of which would be the spot where the sun was vertical at the instant of observation. *The radius of this circle would be equal to the sun's zenith distance*, which, in the case just cited, is 1°. As the observer shifts his position away from the sun, its distance from his zenith will become greater, and his "Circle of equal altitude" proportionately larger, thus rendering his whereabouts more and more uncertain.

It will be seen, therefore, that, so far, the observer can only

* This is sometimes called "The Circle of Illumination"; also "The Terminator," when the moon is referred to.

† These terms, as here applied, are not used in their *celestial* sense, since the *longitude* of a celestial object is measured *on the Ecliptic* from the first point of Aries, and the *latitude* is measured *from the Ecliptic* towards its poles. These terms being utterly at variance with their *terrestrial* signification, where *latitude* is measured *on a meridian* and *longitude on the Equator*, are apt to cause much confusion, and should be abolished by common consent. Surely something better might be substituted.

be sure of his precise position when the sun happens to be exactly in his zenith; at other times it is indefinite, and becomes more so the greater his distance from the sun. From a consideration of the foregoing, "a Circle of equal altitude" may also be designated "a Circle of position."

How to find position of Sun at any given distance.

To find the place on the chart over which the sun is vertical at a given Greenwich time, is very easy, *when you know how.* Since the earth revolves steadily on its axis, any place whose latitude happens to be the same as the declination of the sun at the instant of its meridian passage, must of necessity have the sun vertical at noon; and as Greenwich Apparent Time is equal to the sun's hour angle—or, in other words, to its meridian distance from Greenwich—the required longitude is found by simply turning the Greenwich Apparent Time into arc by Table 18 of Raper.

Briefly, therefore, the sun's declination (corrected for the given Greenwich time) is equal to the latitude of the place; and the Greenwich Apparent Time is equal to the longitude in time, which is always to be reckoned towards the west, since the sun moves in that direction.

To project this on the chart is easy enough *in theory,* but not so easy *in practice.* Suppose "a Circle of position" is required to be drawn with the following data:—

March 7th, 1880, at 1h. 11m. 3·8s., G.M.T., an observer, who was in complete ignorance of his position, found the sun's true altitude to be 50°. To what extent would this enlighten him?

	H.	M.	S.	
Greenwich Mean Time	1	11	3·8	
Corrected Equation of Time	—	11	3·8	
Greenwich Apparent Time	1	00	00·0	=Long. 15° W.

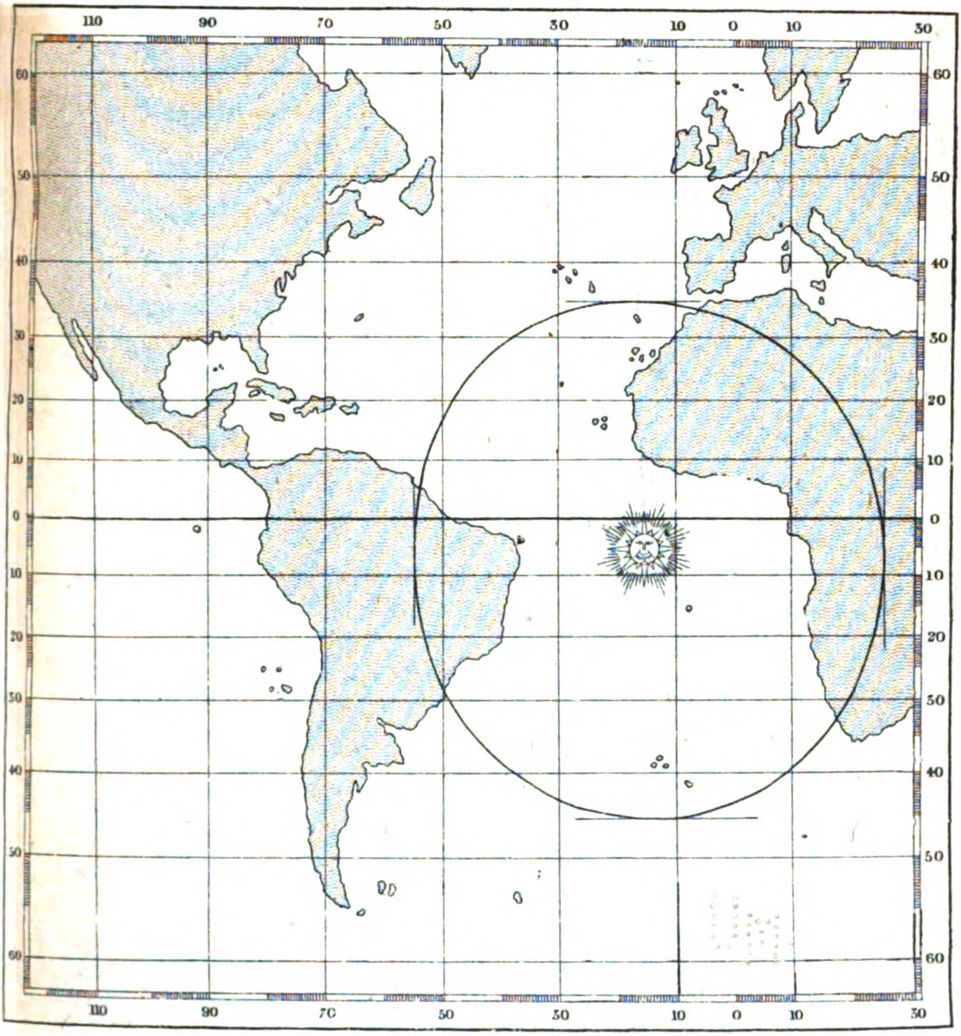
	°	′	″	
☉'s Declination at apparent noon	5	00	18	S.
Correction for 1h., G.A.T. ..	—		58	
☉'s Corrected declination ..	4	59	20	S.

Prick off a point in 4° 59¼′ South and 15° West (see *Chartlet No.* 1). Here the sun will be vertical at the Greenwich time specified. Subtract the observed true altitude (50°) from 90°, which will give 40° for the distance of the sun from the zenith of the observer. Take this amount in the dividers, and, with the above position as a centre, describe a circle. There will now be no difficulty in understanding that for *all* ships on this circle—no matter what part of it—the sun would have an altitude of 50°. Each master would know that he was *somewhere* on this particular circle—neither inside nor outside it, but *on* it. Excepting the certainty that his ship was not on the *land* portion of

What a circle of Equal Altitude teaches.

* *See* explanation (page 491) with respect to effect of Mercator construction on the circle.

CHARTLET Nº 1



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it, this, however, is all he would know, unless aided in some way yet to be described; and reference to the chartlet will show that the circle covers a goodly portion of the globe, leaving him plenty of room to guess.

Place him, however, in the ordinary circumstances of the navigator, and give him his latitude by account. Then, by laying this off on the circle, he would get an *approximate* position; but such knowledge is not always sufficient where the navigation is intricate; nevertheless, poor as it is, *it may sometimes be used to great advantage,* as will be shown further on.

Position on Circle determined by Sounding. The individual in the park determined his whereabouts on the circle by the character of the ground, and, similarly, it is often possible for the navigator to fix the ship's position on it *by the depth of water and character of the bottom.* Bear this in mind, as it is important.

On Chart, Circles of Position appear as irregular ovals. Passing by other methods for the present, the reader's attention is invited to sundry striking points developed by the subject. On scrutinizing *Chartlets Nos.* 1 *and* 2 more closely, it will be seen that the so-called "Circles of position" are not fairly entitled to the name—that, in fact, they are *irregular ovals,* and not true circles.

It will be remembered that it is stated in the chapter on Charts, that Mercator's projection gives a distorted representation of the earth's surface, and here we have another proof of it. Owing to the degrees of latitude being extravagantly drawn out as the Poles are approached, a true circle, when shewn correctly on a Mercator's chart, is made to assume a somewhat elliptical form, having its longer axis in a north and south direction. This feature makes the drawing of the circle in actual practice a matter of some difficulty. The usual way of arriving at it is to calculate a number of longitudes from one sight, retaining in each case the same Polar distance and Altitude, but changing the Latitudes by suitable quantities, say 5° where the scale of the chart is small.*

How to draw Circle on Chart.

When a sufficient number of points have been thus determined, they can be pricked off on the chart, and connected by a free curve drawn with a pliable ruler, which will give the figure with

* As a check against using an *impossible* latitude in the computation, it is as well to know that in the chronometer problem, the sum of the Polar distance, Latitude, and Altitude cannot exceed 180°. Should the addition shew an excess, it proves that the computer made choice of too high a latitude, and he must reduce it accordingly. *When the sum is exactly equal to 180°, it shews the polar limit of the latitude, as the body in such a case is on the meridian.*

Curve of Equal Altitude.

tolerable exactness, and when so drawn, it may be termed "a Curve of position," or "Curve of equal altitude." This, however, would be endless work, and totally unsuited to the wants of the sailor. Happily it is not required.

When the sun passes nearly overhead, the Circle of position is small, and as the observer approaches the sun it becomes yet smaller; until finally, when he has it in the zenith, it vanishes in a point, and this point, as already stated, represents his position on the globe. Conversely, as the observer recedes from the sun, the circle becomes larger, and this brings us to a feature of the very highest importance.

Chartlet No. 2 shews that *when the circle is large*, small portions of it (say an arc of 30′ or 40′) *may be treated as a straight line* without deviating much from the truth; and the larger the circle the nearer any part of its circumference approaches to this condition. This will be apparent by contrasting *Chartlets Nos.* 1 *and* 2, which have straight lines drawn on four of their sides. We see that in *Chartlet No.* 2, where the circle is large, the straight line touching it coincides for a much greater distance with the circumference, and this would be even more marked if the circle in *No.* 1 were say half the size. It is very necessary to retain a good mental grip of this point, as it plays an important part hereafter.

Unnecessary in practice to draw complete circle.

Now, in actual practice, the navigator always knows his latitude within half a degree or so, and it is therefore quite unnecessary to draw the *complete* circle on the chart. He only requires to draw that portion of it which is included between a position say 20′ North, and another 20′ South of his latitude by D.R., and as explained above (*when the circle is large*), this included arc may safely be considered as a straight line.* To this end he merely works his chronometer sight twice over; the first time with a latitude 20′ in excess, and the second time with a latitude 20′ in defect of his position by account. The two resulting longitudes, with the latitude proper to each, he then pricks off on the chart, and connects them by a straight line, which is really an arc of the Circle of equal altitude. Unless the error of the latitude is greater than that assumed, the ship *must* be somewhere on this "Line of position,"† which, for convenience, will

* The straight line is spoken of mathematically either as a *tangent*, or as a *chord, to the curve.*

† As before stated, the Greenwich Time is supposed to be accurately known, otherwise the line will be moved bodily to the *eastward* or *westward*, in proportion to the amount and direction of the error, 4s. being equal to 1′ of longitude. The latitude, however, is not in any way affected by an error in the Greenwich Time.

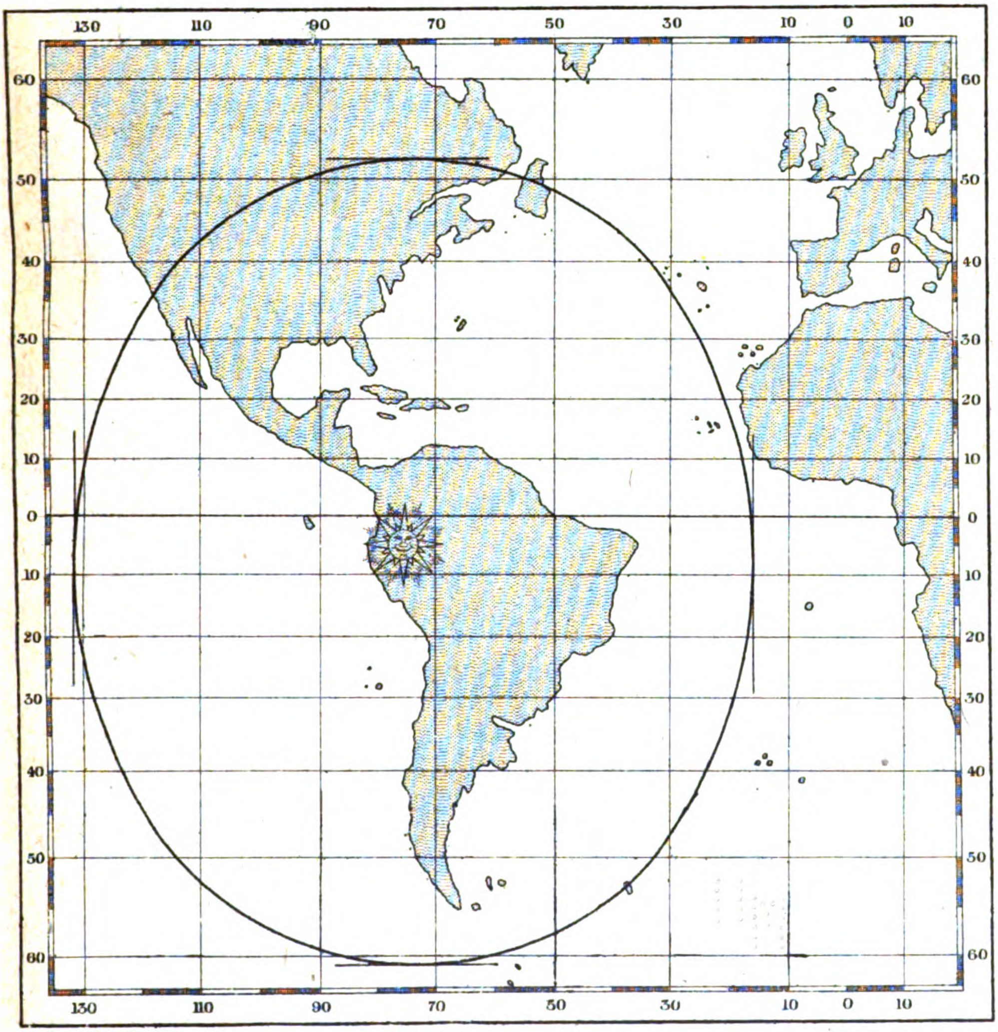
CHARTLET No. 2.

Sunday, March 7th, 1880, at 5h. 11m. 1·2s. mean time at Greenwich, an observer in the Northern Hemisphere found the sun's true altitude to be 33° 17′ 45″.

	H.	M.	S.
Greenwich Mean Time .	5	11	1·2
Corrected Equation of Time .	−	11	1·2
Greenwich App. Time .	5	0	0·0 = Longitude 75° W.

	°	′	″
☉'s Declin. at Greenw. App. noon .	5	00	18 S.
Correction for 5 hours Greenw. App. Time	−	4	52
☉'s corrected Declin. . . .	4	55	26 S.

Therefore at the time specified the sun was vertical to a spot in Lat. 4° 55′ 26″ S., and Long. 75° W.



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henceforth in these pages be termed a "Sumner line," after the American seaman who first brought this useful problem prominently to the notice of the profession. Sumner Lines.

Having got so far in the knowledge of his position, if some kind friend were but able to communicate the *actual* latitude, it would be easy to prick it off on the "Sumner line," and the ship's place would at once be accurately established.

This matter of the "Sumner line" leads to another point of immense value. If we take any portion of the circumference of the circle, and consider it as a straight line (Sumner line), a noteworthy fact stands revealed—the importance of which it is almost impossible to overrate—namely, *that the bearing of the sun is invariably at right angles to this line.* Conversely, a "Sumner line" lies at right angles to the bearing of the sun, so that if either be known the other can be found.

Direction of Sumner Line always lies at right angles to bearing of Sun.

Among other things, this explains why noon is the best time to obtain the latitude. For example, when the sun is on the Meridian it bears either north or south, and if the "Circle of position" be then drawn, that portion of the circumference at right angles to those bearings (when treated as a straight line) will run east and west, or, in other words, will constitute *a parallel of latitude*, upon which the observer must be situated (*vide* Chartlets). Again, when the sun is on the Prime Vertical, it bears either east or west, and is, accordingly, in the best position for determining the longitude, since an observer at such times will be on the "Sumner line" running due north and south, and, therefore, independent of his *exact* latitude. This is also shewn on the Chartlets.

What Sumner Lines teach.

There is, however, a very wide difference in these two cases, which it may be as well to refer to. If the sun left a mark on the earth's surface as it moved over it from east to west, the latitude of this mark would everywhere be the same,* and would be equal to the declination, and therefore, if the observer but knew his distance north or south of this line, he would know his latitude also. That is easily understood.

Now, as the meridian altitude subtracted from 90° gives the distance from the sun, and, consequently, from the mark, the rest is the simplest kind of arithmetic.

For example, let the sun's declination at noon be 20° S., and the observer's zenith 40° to the *southward* of the sun, then his latitude will be 20° S. *plus* 40° S., equal to 60° S. Or, suppose

How latitude is arrived at.

* This is a broad statement, as no account is taken of the constant change in the declination.

the observer's zenith to be 40° *north* of the sun; then, as the sun is 20° *south* of the Equator, and the observer is 40° to the *north* of the sun, he must be 20° *north* of the Equator, which is his latitude.

Now, to ascertain the longitude, we might calculate in the same way if we only had a second sun moving round us from north to south, but we have not, and so the matter needs to be treated in some other form.

How longitude is arrived at.

The latitude, as already seen, may be obtained by *direct* instrumental measurement, being nothing more than the sun's angular distance *from the observer's parallel*, plus or minus the sun's distance from the Equator. This is done every day at noon, and the operation is to a large extent independent of a knowledge of the longitude. In ascertaining the latter, the distance of the sun is taken *from the observer's Meridian*; but excepting in the one particular case, when the observer is on the Equator, and the declination is 0°, this is not susceptible of *direct* measurement. In this special case the sun describes a "Great Circle" round the world, rising due east, and setting due west.* At such times the *Meridian Distance* is obtained *directly*, by merely subtracting the true altitude from 90°, and turning the remainder into time, which of course is the Hour Angle. At all other times the Meridian Distance is obtained by computing the spherical triangle, of which the arguments are the Polar Distance, Latitude, and Altitude, constituting the after-breakfast problem so familiar to all "South Spainers."

Sumner Line shews bearing of land.

But we must get back to the "Sumner line," as it possesses yet another property of very considerable convenience to the navigator. If the line on the chart be extended till it meets a point of land, *it shews the bearing* of that land, and although the exact distance will not be known, we have only to sail on this line till the place is arrived at. On this account the "Sumner line" is frequently termed a "Line of bearing."†

When entering the English Channel in winter, this knowledge may be of great service. The course of homeward-bounders is generally a north-easterly one, so that the south-easterly bearing of the sun in the forenoon is well adapted to give such a direction to the line as will cause it to strike some part of the coast.

* *Vide* foot-note, page 493.

† Seamen of the old school (when chronometers were more scarce than now), are familiar with the plan commonly adopted long before Sumner's time, of running down their easting or westing on the parallel of the port bound to. This was nothing more than sailing on a 12 o'clock "Sumner line."

When the "Sumner line" happens to pass rather wide of a place which would make a suitable landfall, the difficulty can be circumvented by ruling through the desired point a second line parallel to the first, and so shaping the course as to get on to this new line as quickly as possible. Just as though in a strange town you were directed to a shop some distance ahead on the opposite side of the street, your first move would naturally be to cross over, and then resume your walk in the same direction, knowing that you are bound to come to it in time, and only require to keep a good look-out till you do so.

How to make Sumner Line pass through any given point.

Instead of laying down a "Sumner line" by working a sight with *two* assumed latitudes, and pricking them off with their respective longitudes, *half* of the labour may be saved by recollecting *that the "Sumner line" runs at right angles to the sun's true bearing,* therefore, if the sun's bearing be known, it is easy to lay down the "Sumner line." To do this, work the sight *once only,* using the latitude by account, and mark the resulting position on the chart. Open Burdwood or Davis, or turn to the A B C tables, and find the sun's true bearing, employing for this purpose the hour-angle just found, and the same latitude and declination. Rule a line through the chart position at right angles to the sun's true azimuth, and you have the "Sumner line" as before.

Best way of laying down Sumner Line

Here a word of caution is necessary. When the sun's altitude is very high, say 85°, the circle is small; and if even a trifling portion of the circumference be then taken, it will be found considerably curved, and the azimuth of the sun as measured from the two extremes of the arc will appreciably differ; so that the "line of bearing" is not altogether so reliable as it would be if the altitude were lower, and the circle proportionately larger. However, as this problem is more likely to be used in winter than summer, such a case will scarcely arise in practice. Nevertheless, it is well to bear it in mind.

The practicability having already been pointed out, of fixing a ship's position on the "Sumner line" by a cast of the lead, it remains to shew another mode of doing so by the bearing of a distant object.

It is essential in this case that the sun should be either pretty much in the same or contrary direction to the object of which the bearing is taken. Should the sun bear either exactly over it or in the contrary direction, the "cut" will be a right-angled one; and in proportion to the difference of the bearing of the

How to fix position on Sumner Line by bearing of distant land.

the observer's zenith to be 40° *north* of the sun; then, as the sun is 20° *south* of the Equator, and the observer is 40° to the *north* of the sun, he must be 20° *north* of the Equator, which is his latitude.

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The practicability having already been pointed out, of fixing a ship's position on the "Sumner line" by a cast of the lead, it remains to shew another mode of doing so by the bearing of a distant object.

It is essential in this case that the sun should be either pretty much in the same or contrary direction to the object of which the bearing is taken. Should the sun bear either exactly over it or in the contrary direction, the "cut" will be a right-angled one; and in proportion to the difference of the bearing of the

How to fix position on Sumner Line by bearing of distant land.

sun and object, so will the angle of intersection of the two lines be more or less favourable. If, for example, the sun bears two points to the right or left of the object, the "cut" will have an angle of six points, which is very good, but the nearer it is to eight points the better. If the object be a long way off—say 40 to 50 miles—it is necessary to take the bearing with great care. A method of doing this with the utmost accuracy will be given further on. An error of 1° at 50 miles would throw out the ship's position nearly one mile. As the sun's position can be laid down on the chart at any time, this method may be regarded as a mode of fixing the ship's position by cross bearings; a shore object being used for one bearing, and the sun for the other.

Dangerous places safely navigated by Sumner Lines.

An example will now be given, accompanied by a chartlet, to demonstrate the many great advantages of the "Sumner line" in cases of critical navigation. *It will prove the practicability of sailing in absolute safety, and without losing distance, round dangerous shoals, when neither the latitude nor longitude of the ship is more than approximately known.*

The observations here detailed were actually made by the author when commanding the Pacific Co.'s steamship *Galicia*, but the date has been altered to suit the Nautical Almanac for the year in which this book first saw the light. The astronomical elements are given on page 775.

A special bit of navigation.

On the morning of October 24th, 1881, the steamship *Galicia*, being bound to Monte Video, was steering N. 29° E. (true), 12 knots, the intention being to pass outside the French, Astrolabe, and English banks.

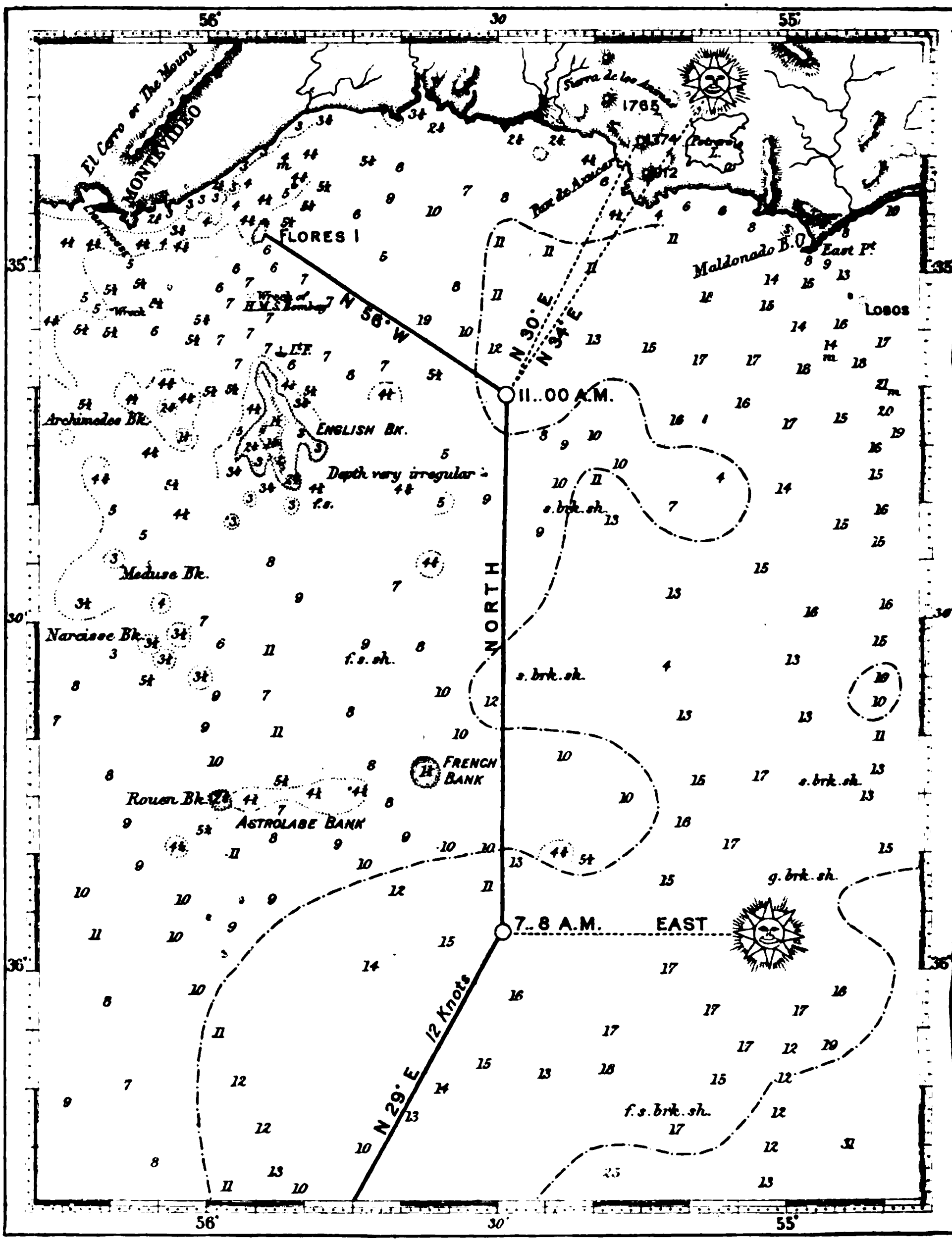
At 7h. 8m. A.M. App. Time at Ship, a cast of the lead was taken in 15 fathoms, sandy bottom, and the following observation was made to get a "Sumner line," by which to keep clear of the shoals.

	H.	M.	S.	
G.M.T.	10	34	23·6	A.M. same date. —☉— True Alt. 20° 40′.
Corr. Equa.	+	15	44·2	
G.A.T.	10	50	7·8	

Position by acc. { Lat. 35° 57′ S / Long. 55° 26′ W.

	°	′			H.	M.	S.
Polar distance	78	7	. . .	0·009409			
Lat. by acc. .	35	57	. . .	0·091767			
-☉- True Alt.	20	40		9·585272			
				9·861996			
	134	44		9·548444 =	4	51	52·2
					12		
Half Sum . .	67	22					
Remainder .	46	42					
			App. time at Ship .		7	8	7·8
			App. time at Greenw.		10	50	7·8
			Long. in time . . .		3	42	0·0 = 55° 30′ W

CHARTLET No. 4.



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Accordingly, Latitude 35° 57′ S., Longitude 55° 30′ W., were pricked off on the chart. Next, Burdwood was opened at page 65, and under declination 12°, and opposite 7h. 8m. A.T.S., the sun's true bearing was found to be 90°, or East. Therefore, a North and South "Sumner line" was ruled through the ship's position.

Now, in accordance with what has already been stated, the ship must be *somewhere* on this line; and as it trended due North and South, owing to the *sun being on the Prime Vertical*, the exact *longitude* was a matter of certainty, and the soundings seemed to indicate that the latitude by D.R. was pretty correct. Looking at the line on the chart, it is evident, let the latitude be what it may, that if the ship were steered upon it, she would go clear of danger. This was done, and the ship's course then became North (true). *As a precaution the lead was kept going, to guard against a westerly set of the tide or current.*

About 10 A.M. high land was sighted a little on the starboard bow, and at 11 A.M. the Pan de Azucar (a mountain 1374 feet high) was recognised, bearing N. 30° E. (true). Its vertical sextant angle—*measured on and off*—was 0° 26′ 45″, eye 28 feet. Immediately an observation was made to get a second "Sumner line," as the sun was favourably situated for crossing it with the bearing of the mountain. A cast was also taken in 11½ fathoms, mud. **Rio de la Plata.**

	H.	M.	S.		
G.M.T.	2	26	16·6	P.M. same date.	-☉- True Alt. 63° 6′
Corr. Equa.	+	15	45·3		
G A.T. . .	2	42	1·9		

Position by acc. { Lat. 35° 10′ S. / Long. 55° 30′ W.

	°	′				H.	M.	S.
Polar distance	78	3	. . .	0·000515				
Lat. by acc. .	35	10	. . .	0·087523				
-☉- True Alt.	63	6		8·507014				
				9·626895				
	176	19		8·230947	=	0	59	58·1
						12		
Half Sum . .	88	9½						
Remainder . .	25	3½						
			App. time at Ship .			11	00	1·9
			App. time at Greenw.			14	42	1·9
						H.	M.	S.
			Long. in time . . .			3	42	0·0 = 55° 30′ W.

This position was duly pricked off, and as Burdwood does not give the azimuth when the altitude exceeds 60°, recourse was had to Towson's handy tables,* page 72, where, by a very few figures, the sun's true bearing was determined to be N. 34° E. A "Sumner line" at right angles to this (N. 56° W. true) being ruled

* "Practical Information on the Deviation of the Compass, for the use of Masters and Mates of Iron Ships." By J. T. Towson. The Tables referred to being confined to 26½° of declin. are superseded by Lecky's A B C Tables, now greatly extended and published separately; and by Goodwin's *Azimuth Tables for the Higher Declinations.*

through the chart position, was found to lead in safety round the north-eastern edge of the English Bank, and strike the island of Flores. This course was steered with every confidence, and in three-quarters of an hour the lighthouse was made dead ahead. Meanwhile the "Sumner line" was cut by laying off on the chart the bearing of the "Pan de Azucar," with the result that it gave a position agreeing exactly with the one by D.R., and further corroboration was found in the soundings, which tallied to a nicety. The distance of the mountain was calculated from the observed vertical angle, and found to be 24½ miles. The measurement on the chart proved to be the same.* It was quite a triumph to find all these things in agreement.

Distance of land by Vertical Angle of same.

Here we have as good an example as could well be selected, of the immense value of the "Sumner line" when making the land, or dodging round shoals. It is necessary to observe that the chronometers had been rated a few days before at Sandy Point, in the Strait of Magellan, so that the longitude of the "Sumner line" could be depended upon as correct, otherwise it would have been imprudent to skirt the banks so closely. In laying off "Sumner lines" on the chart, the navigator is strongly recommended to use Field's Parallel Ruler, which will be found very handy for this and similar purposes.

By way of practice, the reader can work out the following observations, which were made going up the Irish Channel:—

Tuesday, June 8th, 1880, at 3h. 4m. P.M., the s.s. *British Crown* passed one mile S.E. of Tuskar lighthouse, and shaped a course up the George's Channel N. 31½° E., the speed over the bottom varying from 9 knots per hour against the ebb, to 14½ knots with the flood.

Field's Parallel Ruler.

In every case the correct Greenwich Mean Time is referred to. The courses and bearings are by Lord Kelvin's standard compass *reduced* to true. Eye 24 feet. No index error. The exact position of the ship was ascertained from time to time by bearings of the land, and horizontal angles laid down with the Station Pointer. In two instances *vertical* sextant angles of Croghan Hill—*measured on and off the arc*—were taken as a check, and coincided beautifully with the other determinations. The observations were made by the writer singlehanded, and the chronometer times taken by an officer. Had there been an assistant to permit of the observations being made simultaneously, of course it would have been easier, but the close agreement of the results shews what can be done by trying. The chart used was Admiralty Sheet No. 1825 B. The reader is recommended, before going into the calculations, to lay off the

* The writer has brought out a small book (pocket size), entitled "The Danger Angle and Off-shore Distance Tables," whereby a ship's distance from the coast may be taken out by simple inspection. It can be procured from the publishers of this work, and other nautical booksellers. (Price 4s. 6d.).

ship's position corresponding to the various times of observation. This is easily done by starting at one mile S.E. of Tuskar, and ruling a light pencil line with Field's Parallel Ruler in the direction of N. 31½° E. true. Upon this lay off the ship's position at 5h. 28m. 16s.; 5h. 45m. 0s.; 6h. 10m. 19s.; 6h. 37m. 0s.; 7h. 51m. 53s. and 8h. 15m. 8s. When working out the Sumner lines, use a latitude expressly in error some 10′, so that the perfection of the method may be fully demonstrated.

4h. 4m. 0s. P.M. Lucifer Shoals lightvessel abeam, distant about 4¾ miles.

5h. 28m. 16s. $\underline{\odot}$ 25° 57′. Slieve Boy N. 75½° W. Position by bearings, &c., 52° 33′ 7″ N., and 5° 50′ 0″ W. Position by "Sumner line" crossed with bearings of Slieve Boy 52° 33′ 0″ N., and 5° 49′ 37″ W.

5h. 33m. 40s. $\underline{\odot}$ 25° 7¾′. Croghan Hill N. 54° W. ∧ 0° 43′ 50″ = 23 miles distant against 22¾ miles by bearings, &c., which latter gave position 52° 34′ 8″ N. and 5° 49′ 10″ W. Position by "Sumner line" crossed with bearing of Croghan Hill 52° 34′ 5″ N. and 5° 49′ 45″ W.

5h. 45m. 0s. South Arklow lightvessel bore N. 43¼° W., distant nearly 8 miles.

6h. 10m. 19s. $\underline{\odot}$ 19° 36′. Croghan Hill N. 72¾° W. ∧ 0° 42′ 10″ = 23½ miles distant, agreeing exactly with following position by bearings, &c., 52° 40′ 50″ N. and 5° 42′ 30″ W. By "Sumner line" crossed with bearing of Croghan Hill 52° 40′ 55″ N. and 5° 43′ 0″ W.

6h. 23m. 54s. $\underline{\odot}$ 17° 34½′. Croghan Hill N. 79¼° W. Observed horizontal angles as follows: Mt. Leinster 18° 45′ Crogan Hill 45° 34′ Great Sugar Loaf. Which gave position 52° 43′ 20″ N. and 5° 40′ 0″ W., against 52° 43′ 12″ N. and 5° 38′ 30″ W., by "Sumner line" cut by Croghan Hill.

6h. 37m. 0s. Wicklow Head lighthouse bore N. 48¼° W.

7h. 51m. 53s. $\underline{\odot}$ 5° 30′. Summit of Bardsey Island, in the *opposite* direction to the sun, bore S. 54¼° E., distant about 27½ miles. The sextant angle between Croghan Hill and the sun's nearest limb was 53° 57′. Position 53° 1′ 50″ N. and 5° 23′ 0″ W., against 53° 2′ 5″ N. and 5° 23′ 40″ W., by "Sumner line" cut by Bardsey. In this case the bearing of Croghan Hill was found by first getting out the sun's azimuth from Burdwood, and then applying to it the horizontal angle measured between it and Croghan Hill. The method of doing this will be given in another chapter.

8h. 15m. 8s. The final position of the ship was 53° 6′ 40″ N., 5° 18′ 50″, W. The horizontal angle between the Great Sugar Loaf and the sun's nearest limb was 30° 45′, the sun having an altitude of *about* 2° 45′. At the same time, nearly, the horizontal angle between Holyhead Mountain and the summit of Bardsey was 74° 40′.

It must be clearly understood that the *distinctive* feature of Sumner's process is that a single altitude taken at any time is made available for determining a line on the chart on some part of which line the ship is situated. The discovery of this fact by Captain Thos. H. Sumner appears to have been accidental, and is thus recorded in his book published in Boston in 1843:— "Line of bearing."

"Having sailed from Charleston, S.C., 25th November, 1837, bound for Greenock, a series of heavy gales from the westward promised a quick passage. After passing the Azores, the wind prevailed from the southward, with thick weather; after passing longitude 21° W., no observation was had until near the land, but soundings were had not far, as was supposed, from the edge of the bank. The weather was now more boisterous, and very thick, and the wind still southerly.

Arriving about midnight, 17th December, within 40′. by dead reckoning, of Tuskar light, the wind hauled S.E. (true), making the Irish Coast a lee shore. The ship was then kept close to the wind, and several tacks made to preserve her position as nearly as possible until daylight, when, nothing being in sight, she was kept on E.N.E. under short sail, with heavy gales. At about 10 A.M. an altitude of the sun was observed, and chronometer time noted; but having run so far without any observation, it was evident that the latitude by dead reckoning was liable to error and could not be entirely relied upon."

However, the longitude by chronometer was determined, using the uncertain D.R. latitude, and the ship's position fixed in accordance. A second latitude was then assumed 10′ to the north of the last, and working with this latitude a second position of the ship was obtained; and again a third position by means of a third latitude still 10′ further north.

Captain Sumner's discovery.

On pricking off these three positions on the chart it was discovered that the three points were all disposed in a straight line lying E.N.E. and W.S.W., and that when this line was produced in the first-named direction, it also passed through the Smalls light. The conclusion arrived at was "that the observed altitude must have happened at all three points, at the Smalls light, and at the ship at the same instant of time." The deduction followed that, though the absolute position of the ship was doubtful, yet the true bearing of the Smalls light was certain, provided the chronometer was correct. The ship was therefore kept on her course, E.N.E., and in less than an hour the Smalls light was made bearing E. by N. ½ N. and close aboard. The latitude by D.R. turned out to be 8′ in error.

It will be observed that it did not then occur to Sumner to cross his line of position with a second one, and so get a definite "Fix." (See next chapter.) Perhaps the sun did not give him the opportunity.

Honour where honour is due.

This appears to have been the first recorded application of the principle, and to have furnished the foundation of the system which Sumner worked out and published half a dozen years later. In the first year of publication of his book an order was given to supply it to every ship in the United States Navy. The Bureau of Navigation at Washington adopted the same course with respect to "Wrinkles in Practical Navigation," an example followed later on by our own Admiralty.

In low latitudes, with declination and latitude nearly equal, a good graphic illustration is obtainable of the principle underlying Sumner's Method, together with the ship's geographical position, as practised by Captain T. S. Angus, of the P. and O. Observe the altitude, while azimuth is yet large, directly Zenith Distance is small enough to measure on the chart with a pair of dividers; plot position (latitude = declination, longitude = Greenwich Apparent Time); and, from this spot as centre, describe an arc of a circle with Zenith Distance as radius. Then ship is somewhere on this arc. Wait till azimuth changes sufficiently to give a good cut, and repeat the operation. The intersection gives geographical position of ship without calculation. If ship

Simplicity itself

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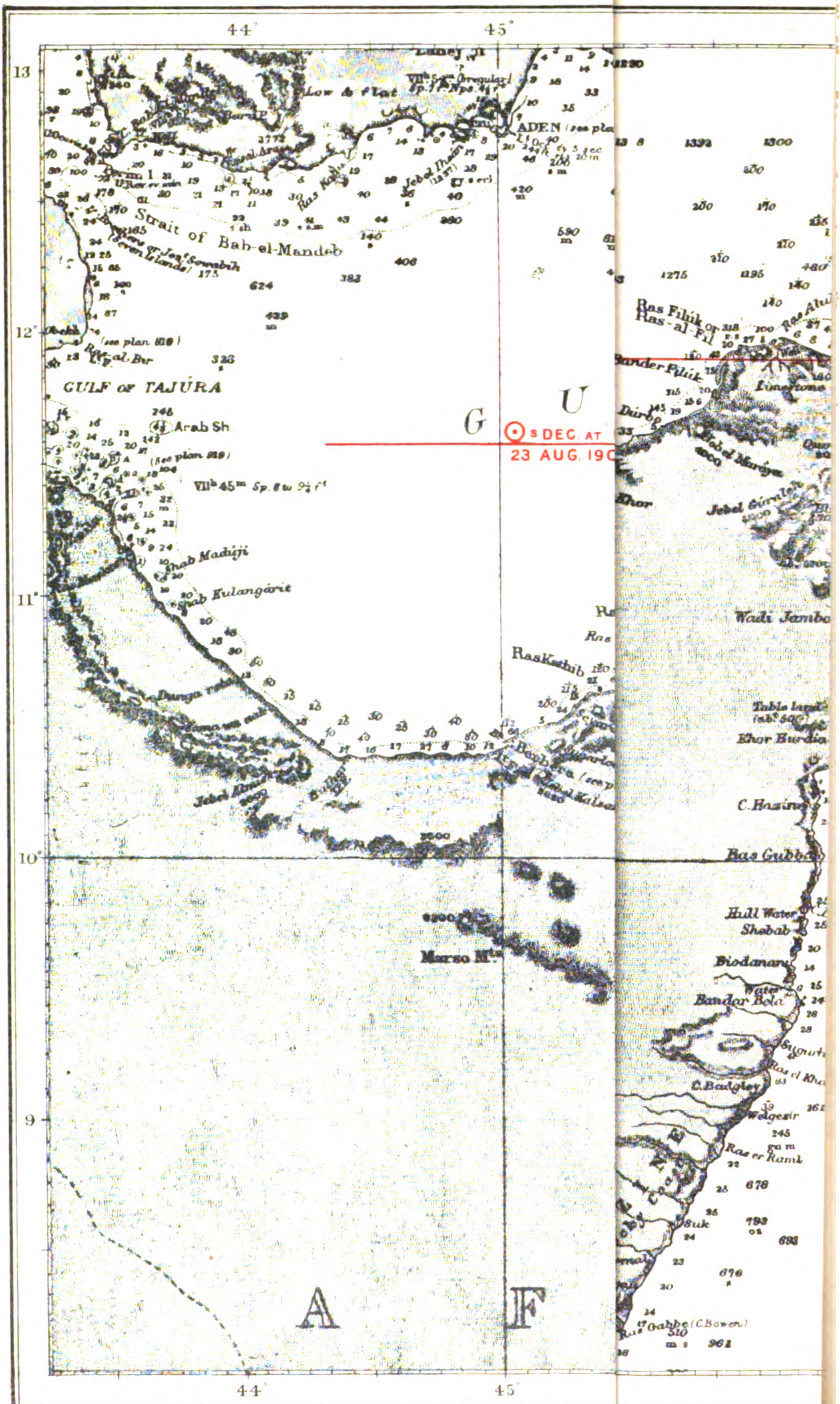

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The following sights were taken near noon to get a position by Sumner's Method projected on to the chart. A strong S.W. monsoon was blowing, and the horizon was somewhat hazy. The first altitude was about 18min. from noon, so as to give a good longitude; the second about 4min. before noon; and the third and fourth later. The first sight was reduced to the fourth by shifting the position of the sun's centre on the chart at the time of the first sight—N. 46° W. 4·5 miles—this being the ship's run in the interval, and, using the new position as a centre, to sweep the first arc, using Zen. Dist. as radius. It will be noticed that the second and third sights happened to be equal altitudes. Captain Angus's sights and working.

22nd August, 1900.

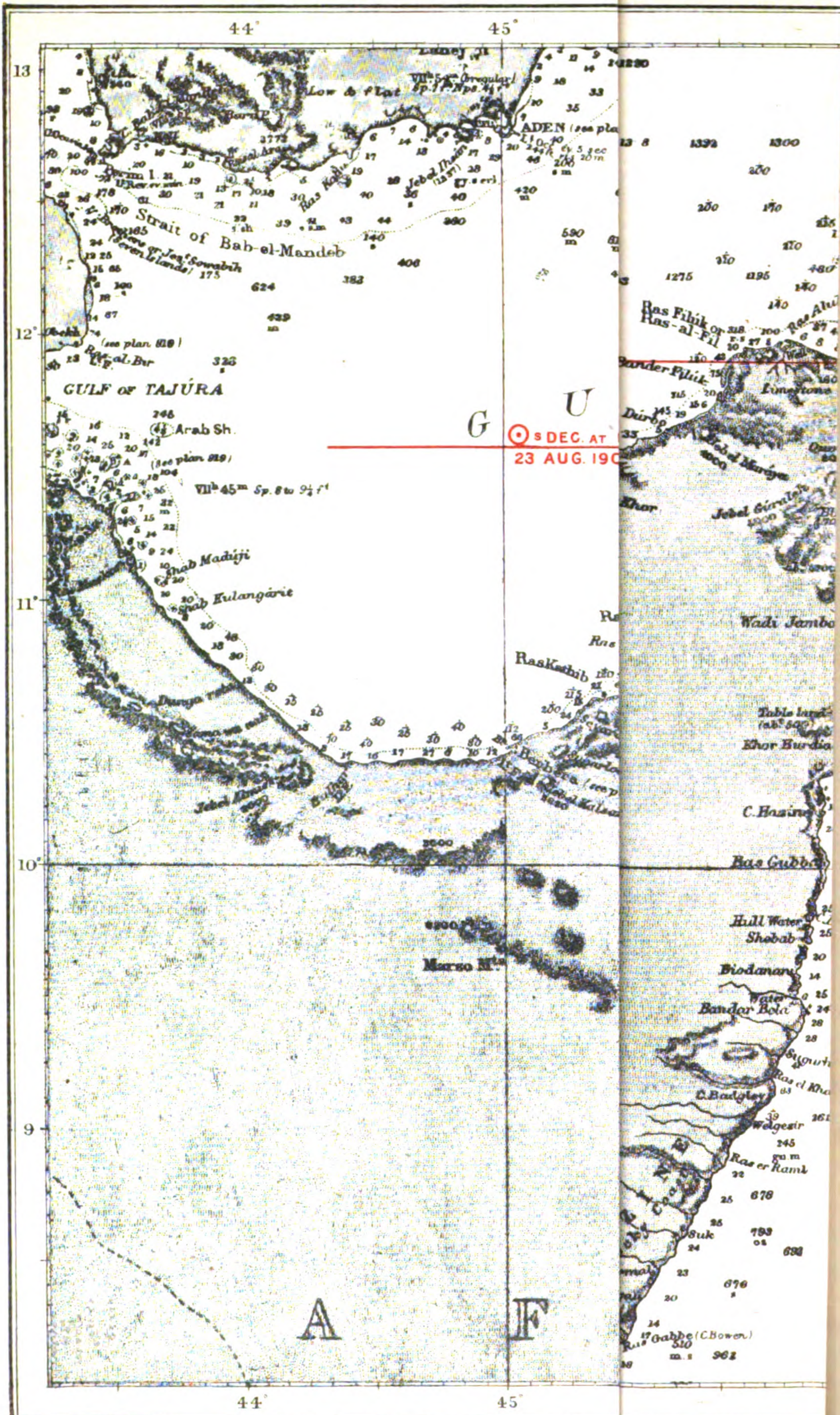
☉'s Declination corrected to Noon 11° 54′ 38″ N.

Equation of Time.—2m. 51s. on Mean Time.

	First Sight. H. M. S.	° ′	*Second Sight.* H. M. S.	° ′
Chron.	20 22 56	☉ 85 59	20 36 28	☉ 88 17
Error	− 5 20	+ 10	− 5 20	+ 10
	20 17 36	86 9	20 31 8	88 27
Eq. Time	− 2 51		− 2 51	
		Zen. Dist. 3 51		1 33
	20 14 45		20 28 17	
☉ East of Greenwich	3 45 15		3 31 43	
In arc	56° 18·7′		52° 55·7′	

	Third Sight H. M. S.	° ′	*Fourth Sight.* H. M. S.	° ′
Chron.	20 38 13	☉ 88 17	20 41 14	☉ 88 5
Error	− 5 20	+ 10	− 5 20	+ 10
	20 32 53	88 27	20 35 54	88 15
Eq. Time	− 2 51		− 2 51	
		Zen. Dist. 1 33		1 45
	20 30 2		20 33 3	
☉ East of Greenwich	3 29 58		3 26 57	
In arc	52° 29·5′		51° 44·2′	

Resulting Position at Fourth Sight is 10° 23′ N., 52° 38′ E.



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The following sights were taken near noon to get a position by Sumner's Method projected on to the chart. A strong S.W. monsoon was blowing, and the horizon was somewhat hazy. The first altitude was about 18min. from noon, so as to give a good longitude; the second about 4min. before noon; and the third and fourth later. The first sight was reduced to the fourth by shifting the position of the sun's centre on the chart at the time of the first sight—N. 46° W. 4·5 miles—this being the ship's run in the interval, and, using the new position as a centre, to sweep the first arc, using Zen. Dist. as radius. It will be noticed that the second and third sights happened to be equal altitudes.

22ND AUGUST, 1900.

⊙'s Declination corrected to Noon 11° 54′ 38″ N.

Equation of Time.—2m. 51s. on Mean Time.

	First Sight. H. M. S.	° ′	*Second Sight.* H. M. S.	° ′
Chron.	20 22 56	⊙ 85 59	20 36 28	⊙ 88 17
Error	− 5 20	+ 10	− 5 20	+ 10
	20 17 36	86 9	20 31 8	88 27
Eq. Time	− 2 51		− 2 51	
Zen. Dist.		3 51		1 33
	20 14 45		20 28 17	
⊙ East of Greenwich	3 45 15		3 31 43	
In arc	56° 18·7′		52° 55·7′	

	Third Sight H. M. S.	° ′	*Fourth Sight.* H. M. S.	° ′
Chron.	20 38 13	⊙ 88 17	20 41 14	⊙ 88 5
Error	− 5 20	+ 10	− 5 20	+ 10
	20 32 53	88 27	20 35 54	88 15
Eq. Time	− 2 51		− 2 51	
Zen. Dist.		1 33		1 45
	20 30 2		20 33 3	
⊙ East of Greenwich	3 29 58		3 26 57	
In arc	52° 29·5′		51° 44·2′	

Resulting Position at Fourth Sight is 10° 23′ N., 52° 38′ E.

In working the following sights no allowance is made for ship's run, as the interval between the first and last sights was only five minutes, during which the *China* made about N. 82° W., 1 mile. The sun's declination was also assumed to be constant for that short interval. Neither assumption would make any appreciable difference in the result.

23RD AUGUST, 1900.

⊙'s Declination corrected from Noon 11° 34′ 5″ N.

Equation of Time.—2m. 36s. on Mean Time.

	First Sight.		*Second Sight.*	
	H. M. S.	° ′	H. M. S.	° ′
Chron.	20 56 16	⊙ 88 47·5	20 58 51	⊙ 89 1
	− 5 26	+ 10	− 5 26	+ 10
	20 50 50	88 57·5	20 53 25	89 11
Eq. Time	− 2 36		− 2 36	
	20 48 14	Zen. Dist. 1 2·5	20 50 49	0 49
⊙ East of Greenwich	3 11 46		3 9 11	
In arc	47° 56·5′		47° 17·7′	

	Third Sight.	
	H. M. S.	° ′
Chron.	21 1 8	⊙ 88 49·5
	− 5 26	+ 10
	20 55 42	88 59·5
Eq. Time	− 2 36	
	20 53 6	Zen. Dist. 1 0·5
⊙ East of Greenwich	3 6 54	
In arc	46° 43·5′	

Resulting Position at Third Sight was 12° 23·5′ N., 47° 17·5′ E.

CHAPTER XII.

"DOUBLE ALTITUDES."

That very distinguished authority, Lord Kelvin, in alluding to Sumner's method of "Double Altitudes," is credited with having said in the course of a lecture at Glasgow, "that it would be the greatest blessing to navigators, both young and old, if every other method of ordinary navigation could be swept away." When one considers that the "Double Altitude" problem—not Ivory's, or Riddle's, or the method by natural sines, but the "Double Altitude" problem as *now* practised—gives the Latitude, Longitude, and Azimuth, *all at one working*, the learned Professor's remark seems more than justified. Pre-eminence given to Double Altitudes

The chief virtue of this powerful problem consists in utilizing observations taken almost at any hour of the day, so that one is rendered gloriously independent of the 9 o'clock sight, and the time-honoured Meridian Altitude. Of all others, therefore, this is the problem to which the navigator should devote his most serious attention.

In the last chapter it is shewn how a single altitude of the sun gives a "Circle or Curve of position," upon some part of which the observer must be. If, then, after an interval, during which the sun has travelled sufficiently to the westward, *another* altitude be taken, a second "Circle of position" will be obtained, upon some part of which the observer must likewise be. Now, since he is *somewhere* on *both* of the circles, he must of necessity be at their point of intersection, which is the only place that can satisfy the twofold condition. It is true that the circles intersect each other at *two* points, but these are *generally* wide apart—perhaps in opposite hemispheres—and surely the observer knows his whereabouts within a handful of degrees. It will be evident, therefore, that the "Double Altitude"* problem is nothing more Intersection of circles. Azimuth will tell him.

* Raper finds fault with this term, and suggests "Combined Altitudes." He is right, but its meaning is so thoroughly established among the seafaring community, that any attempt to change it would be questionable wisdom.

than the operation detailed in the last chapter, repeated after a suitable interval. *Chartlet No.* 3 illustrates this. The circles in it are those which have already been separately given. They are now 'combined,' to exemplify the method, and the data belonging to each presented to the reader in a complete form.

MARCH 7TH, 1880.

Example of Double Altitude.

About 11 A.M. Apparent Time at Ship, an observer *in the Northern hemisphere* found the sun's true altitude to be 50°, when a chronometer shewed 1h. 11m. 3·8s. of G.M.T.

After an interval of four hours, the same observer, at 5h. 11m. 1·2s. of G.M.T., found the sun's true altitude to be 33° 17′ 45″. Required his Latitude and Longitude; also the sun's true azimuth at each observation.

Reference to the chartlet will shew that the circles intersect in Latitude 32° 23′ N., and Longitude 30° W. The sun's azimuth at the first observation was S. 23¾° E. and S. 57½° W. at the last one. The "Sumner lines" are at right angles to these bearings, and of course cut each other at the same point that the circles do. Considering them as "*Lines of bearing,*" if the ship were sailed on the first "Sumner line," she would fetch Vigo in one direction, or the West India Islands in the other. If she were sailed on the second "Sumner line," she would fetch either Sierra Leone or Baffin's Bay.

"Astronomical cross-bearings"

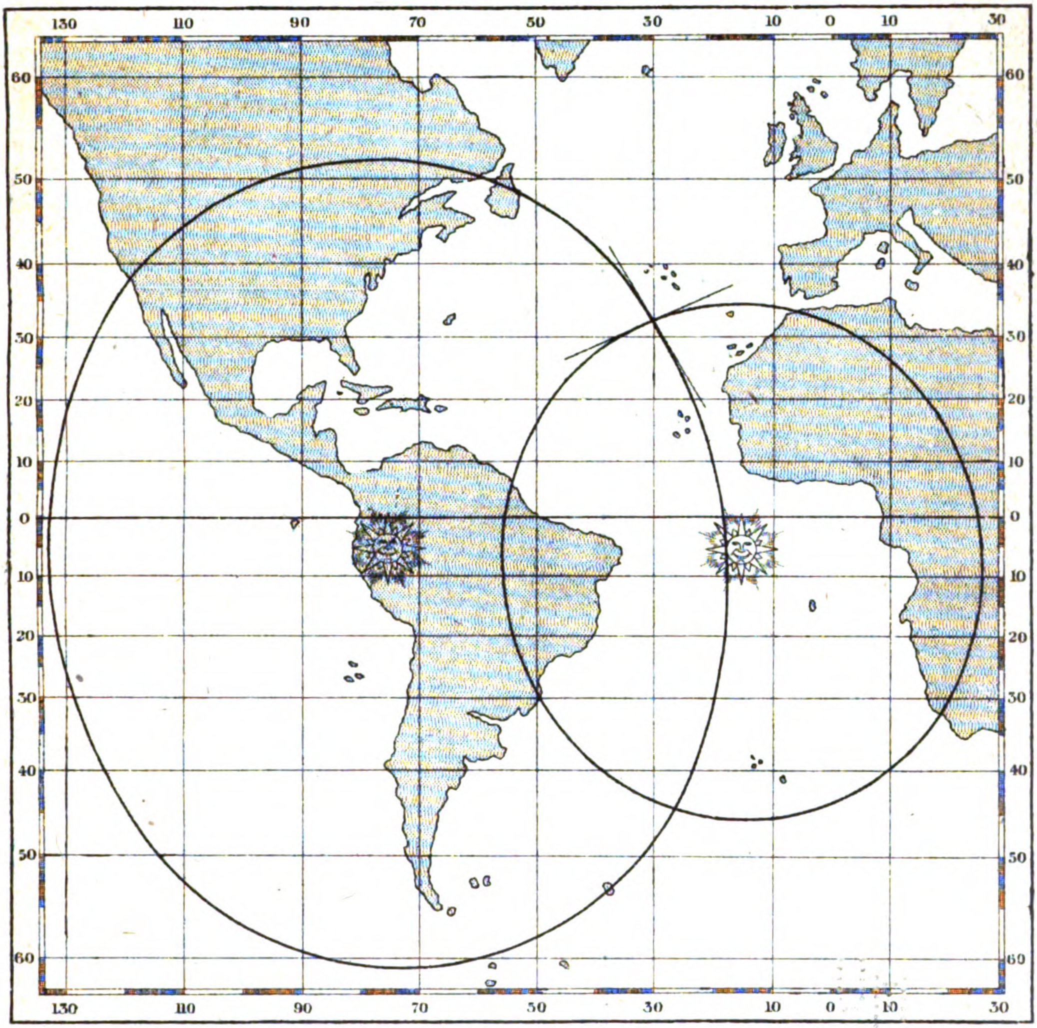
This method may be considered as a means of determining the ship's place *by astronomical cross-bearings;* the first bearing of the sun being taken when convenient, and its position at that moment laid down on the chart; and the second, or *cross-bearing,* after an interval sufficient to allow the requisite change in the sun's position. In the example before us, the bearings cross at an angle of 81¼°, which, being nearly a right angle, gives a very favourable "cut."

In practice, the ship is very seldom stationary between the observations, and if it be required (as is customary) to know her position at the *last* one, the first circle must be moved *bodily* to the same distance and in the same direction as the ship has sailed in the interval. When dealing with the "Sumner lines," the same rule of course holds good: the first one must be transferred *parallel with itself,* according to the course and distance made good between sights. *Then* its point of intersection with the second "Sumner line" will be the ship's place as required.

How to manage when ship shifts position between observations.

In sea-going practice, to find the latitude and longitude by this method, take two altitudes of the sun, with such an interval between them as will give a difference of bearing of *at least*

CHARTLET Nº 3



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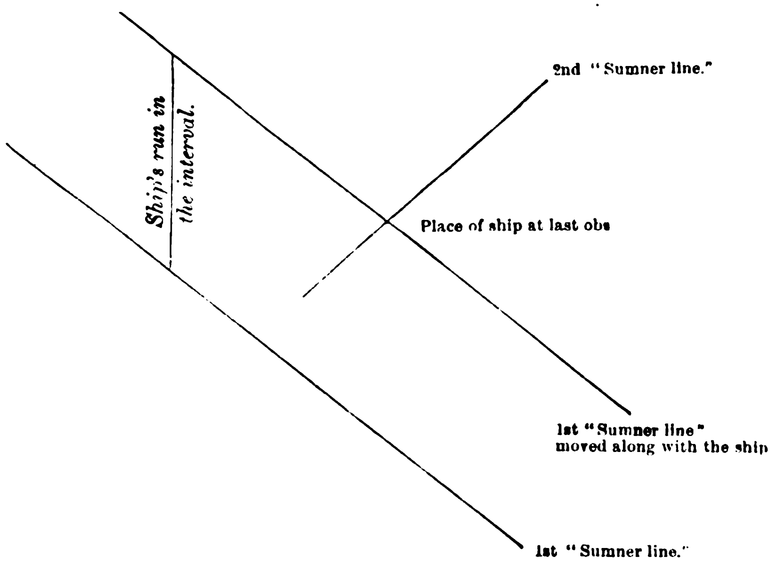
three points, but the nearer to eight points the better—same rule in fact as in taking cross-bearings of the land, where the place of the ship is most distinctly marked when the pencil lines have a good square crossing. Work the altitudes separately, using the Latitude by Account and Polar Distance proper to each, and find the respective azimuths by the A B C or other tables. Through each resulting position on the chart, rule a "Sumner line" differing 90° in direction from the sun's true bearing. Take *any* point in the 1st line, and from it draw a 3rd, to represent the ship's run between the observations. Through the end of this 3rd line draw a 4th. parallel to the 1st, and the point at which it cuts the 2nd Sumner line is the place of the ship. Double Altitudes

To prevent confusion, it is better not to draw the 2nd "Sumner line" till the 1st one has been projected for the run of the ship: there need then be but one point of intersection, as in the figure. It might serve to make this transference of the 1st "Sumner line" better understood, if we were to imagine it something the ship could carry with her, and drop *at the correct*



angle, at the instant of making the observation which was to cross it with the 2nd "Sumner line."

Now, it is not always convenient to draw "Sumner lines" on a chart. Moreover, to define the "cut" clearly and accurately, it is necessary to use a well-sharpened pencil, to have a chart on a fairly large scale, and that the difference in the sun's bearing Calculation better than "plotting"

Calculation by Sumner's own method too tedious.

be not less than three points,—the two latter of which conditions are unfortunately not always obtainable. Again, if "Double altitudes" be practised daily—as most assuredly they ought to be—constantly plotting the "Sumner lines" would soon disfigure the chart. It may be graphic, but it is also clumsy.*

To avoid all this, and ensure the greatest accuracy the method is capable of, it is advisable to do the whole thing *by calculation from first to last.* Calculation is better than any construction, inasmuch as it is absolutely accurate *if the data are accurate.* But the "Double altitude" problem, when worked out in full, *according to Sumner,* is a formidable affair, and the rules at the finish are so complicated as to scare most ordinary seafaring men.

Johnson's Double Altitude Problem the best.

The easier method introduced by the late Mr. Johnson, when Naval Instructor on board Her Majesty's training ship *Britannia,* is therefore a most welcome improvement.† It is short, easily understood, and accurate, and there is little in the whole calculation with which the navigator is not already familiar. Let us now contrast the two methods, and the reader can judge for himself which gives most value for an equal number of figures. The example, of which the figures are here given, is the one already presented graphically to the reader in chartlets 1, 2, and 3.

* Commander E. D. Downes, R.N. (afterwards Lord Ellenborough) recommended a plan which spares the chart at the expense of the work-book; and it can be adapted not only to double chronometers but also to ex meridians. His rules are :—(1) Draw a horizontal line in the work-book to represent the latitude; (2) On it set off the two longitudes at a distance from each other of ·1 inch to 1′ of longitude; (3) From these two points lay down the Sumner lines, and from their point of intersection draw a perpendicular to the line of D.R. latitude. Then the longitude at the point struck by the perpendicular is the longitude required, and may be measured from either point of the longitudes. As this diagram is practically on a plane chart, the diff. lat. will be too great; and the perpendicular is taken to the traverse table as a distance, with D.R. lat. as course; and the true diff. lat. is found by inspection in the diff. lat. column. This saves all trouble with a chart, and does not hurt the work book. Lord Ellenborough used the example on page 531 to prove his case. On the back of the Pilot Chart of the North Atlantic, for September, 1902, issued by the United States Hydrographic Office, there was an admirable exposition of the modern Sumner methods by Lieutenant (now Captain) G. W. Logan, U.S. Navy, in which the writer gave examples of the graphic system of plotting a Sumner on a Mercator Chart, by scale like Lord Ellenborough, and on squared paper. These graphic methods have also been treated by other writers on Sumner.

† "*On finding the Latitude and Longitude in Cloudy Weather.*" London: J. D. Potter 145, Minories.

SUMNER'S STYLE OF CALCULATING A "DOUBLE ALTITUDE"—(ROSSER'S ARRANGEMENT).

Assumed Latitude, 32° 15′ N.

	H. M. S.			H. M. S.	
Greenwich Mean Time	1 11 3·8	-☉- True Alt. 50° 00′.	Greenwich Mean Time	5 11 1·2	-☉- True Alt. 33° 17¾′.
Corrected Equation of Time . .	— 11 3·8		Corrected Equation of Time . .	— 11 1·2	
1st Greenwich App. Time . . .	1 0 0·0		2nd Greenwich App. Time . . .	5 0 0·0	

(a)		(b)		(c)		(d)	
94° 59½′	0·00165	94° 55½′	0·00161	94° 59½′	0·00165	94° 55½′	0·00161
32 00	0·07158	32 00	0·07158	32 40	0·07478	32 40	0·07478
50 00	8·42032	33 17¾	9·23481	50 00	8·31189	33 17¾	9·22005
	9·79407		9·86283		9·79723		9·86519
176 59½	8·28762	160 13¼	9·17083	177 39½	8·18555	160 53¼	9·16163
88° 29¾′		80° 6¾′		88° 49¾′		80° 26¾′	
38 29¾		46 49		38 49¾		47 09	

	(a) H. M. S.	(b) H. M. S.	(c) H. M. S.	(d) H. M. S.
Hour Angle	1 4 2		0 56 54	
A.T.S. . .	10 55 58	3 1 8	11 3 6	2 59 7
A.T.G. . .	13 00 00	5 0 0	13 0 0	5 00 0
Long. in Time	2 4 2=	1 58 52=	1 56 54=	2 00 53=
	Long. (a). . 31° 00½′ W.	Long. (b) . . 29° 43′ W.	Long. (c) . . 29° 13½′ W.	Long. (d) . . 30° 13¼′ W.

With Latitude 32° N. (*D*. 40′).

1st observation—Longitude (*a*)	31° 00½′	W.
2nd observation—Longitude (*b*)	29 43	W.
Diff. (*A*)	1 17½	E.
(*B*)	0 59¾	W.
As (*A* + *B*) . . .	2 17¼	. . . . Prop. Log.—(ar. com.) 9·8822
is to (*A*) . . .	1 17½	. . . . Prop. Log. 3660
so is (*D*) . . .	0 40	. . . . Prop. Log. 6532
To Correction . . .	+0 22½	N. . . . . Prop. Log. ·9014
Lesser Latitude	32 00	N.
True Latitude	32° 22½′	N.

With Latitude 32° 40′ N.

Longitude (*c*) . .	29° 13½′	W.
Longitude (*d*) . .	30 13¼	W.
(*B*) . .	0° 59¾′	W.

Longitude (*a*) . .	31° 00½′	W.
Longitude (*c*) . .	29 13½	W.
(*C*) .	1° 47′	W
		9·8822
		3660
(*C*) 1° 47′ Prop. Log. .		2259
Correction . . .	—1° 0½′ E.	·4741
Longitude (*a*) . .	31 0½ W.	
True Longitude .	30° 00′ W.	

NOTE.—When the ship has changed her position between the observations, there is even more work, and also an additional rule to remember.

SAME "DOUBLE ALTITUDE" CALCULATED BY A. C. JOHNSON'S METHOD.

Assumed Latitude, 32° 15′ N.

	H.	M.	S.	
Greenwich Mean Time . . .	1	11	3·8	-☉- True Altitude 50° 00′
Corrected Equation of Time .	—	11	3·8	
1st Greenwich App. Time . .	1	0	0·0	

94° 59½′	0·00165
32 15	0·07277
50 00	8·38276
	9·79526
177 14½	8·25244
88° 37′	
88 37	

	H.	M.	S.	
Hour Angle.	1	1	29	= S. 24° E.
A.T.S. . .	10	58	31	
A.T.G. . .	13	00	00	
Long. in Time	2	1	29	=

1st Longitude 30° 22¼′ W.
2nd Longitude 29 53¾ W.

3°·4) 28·5 (8′·4 Correction for Lat.
272

130
136

Assumed Latitude . .	32°	15′ N.
Correction	+	8½
True Latitude . . .	32°	23½′ North.
1st Longitude	30°	22¼′ W.
Correction	−	22¼
True Longitude . . .	30°	00′ West.

	H.	M.	S.	
Greenwich Mean Time . . .	5	11	1·2	-☉- True Altitude 83° 17¾′
Corrected Equation of Time .	—	11	1·2	
2nd Greenwich App. Time . .	5	0	0·0	

94 55½	0·00161
32 15	0·07277
33 17¾	9·22952
	9·86369
160 28½	9·16759
80° 14′	
46 56½	

	H.	M.	S.	
A.T.S. or Hour Angle	8	0	25	= S. 57½° W.
A.T.G.	5	0	00	
Long. in Time . .	1	59	35	=

2nd Longitude . . .	29°	53¾′ W.
Correction	+	6¼
True Longitude . .	30°	00′ West.

Table C.

☉ Bearing S. 24° E. — 2′·65 × 8′·4 = 22¼′ correction for 1st Long.
☉ Bearing S. 57½ W. — 0′·75 × 8′·4 = 6¼′ " 2nd "

Sum 3·40

Note.—Here we have about 280 figures, including the sun's azimuths, against about 530 by Sumner's Method; or nearly double the number without the azimuths.

THE FOLLOWING IS THE RULE FOR THIS METHOD.*

Johnson's Rules.

I. Let two chronometer observations be taken at an interval of about an hour and a half, or two hours, if possible, provided that the sun's bearing has changed not less than a point and a half, or two points,† and let the first be worked out with the lat., D.R. at the time of observation.

II. Let the lat., D.R., and longitude thus obtained, be corrected for the run of the ship in the interval between the observations, and let the second observation be worked with this corrected latitude. Name these longitudes (1) and (2), and take their difference.

III. The bearing of the sun at each observation is to be taken from an Azimuth Table. In every case they are to be considered as less than 90°: so that when the Tabular bearings exceed 90°, we must subtract them from 180°, and reckon them from the opposite point of the compass; thus N. 122½° W. would be S. 57½° W., and so on.

IV. Enter Table C. (pages 446-451), with the latitude and bearings, and take from it two numbers (*a*) and (*b*), of which take the difference or sum, according as the bearings are in the same or different quarters of the compass. The difference between the longitudes (1) and (2), divided by this difference or sum, gives the correction for the second latitude; and (*a*) and (*b*), multiplied by this correction for latitude, give the corrections for the two longitudes.

V. *To apply the corrections for the longitude.*

When the observations are in the *same* quarter of the compass, allow the corrections *both* to the East, or *both* to the West,	When the observations are in different quarters of the compass, correct the Easterly longitude towards the West, and the Westerly longitude towards the East,

in such a manner as to make the two longitudes *agree*. If they do not agree, they show that the corrections have been wrongly

* Inserted with Mr. Johnson's permission.

† In conformity with his recommendation near bottom of page 466, the writer would prefer to completely ignore the question of the time which should be allowed to elapse between sights, and let rule I. read as follows:—Subject to restrictions presently to be specified, let two chronometer observations be taken with an interval *depending upon sun's change of bearing:* this should not be less than two points.

The method depends, not upon an *interval of time* as such, but upon a *difference of bearing*. No matter how great the interval, if there is insufficient difference of bearing the method falls to the ground.

applied; and herein, as Mr. Johnson says, we have a valuable safeguard against error, peculiar to this method only.

VI. *To apply the correction for the latitude.*

Under the sun's bearing at the time of observation write the *opposite* bearing, and suppose the letters to be connected diagonally; then that connected with the name of the correction for longitude will be the name of the correction for the latitude. Thus, if the correction for the longitude were 6¼′ W., and the sun's bearing S. 57½° W.,

We should write down S. W.

and under it N. E.

Then, as the letter which stands diagonally opposite to W. (the name of the correction for the longitude) is N., the correction for the latitude has to be allowed towards the North: and so on in other cases.

A consideration of the direction in which the "Sumner lines" trend, will give the reason for Rule VI. The reader can also refer back to those in *Chartlet No.* 3, and to the explanation on page 479, *et sequitur.*

An example from actual observation on board ship is given on the following page, to shew the complete working of the method advocated.

Similarity of principle between Rosser's and Johnson's methods.

In 1866, W. H. Rosser brought out an admirable method of treating 'Double Altitudes' by *Logarithmic Tabular Differences,** which, he explains in the preface, is derived from a work by Captain Louis Pagel, of the French Imperial Navy, published in 1847.

Preference given to Johnson.

Rosser's and Johnson's are precisely the same in principle, as, indeed, are all "Double Chronometer" methods; but the details of the process are somewhat dissimilar; many people, however, would on close examination consider this dissimilarity to be more apparent than real. It is very much a case of "A rose by any other name would smell as sweet." Nevertheless, there *is* a dissimilarity—quite enough to swear by.

In both methods there is one all-important factor, namely, the error caused in the Longitude by an error of 1′ in the Latitude. Johnson's factors are expressed in *minutes of arc,* whilst Rosser's are expressed in *seconds of time.* Of course these are convertible terms. Johnson's factors are taken out direct from Table C.

* *The shortest method of finding the Latitude, Longitude, and Azimuth.* London. James Imray and Son.

(merely his own Table I. extended): Rosser's factors are derived from a manipulation of the *Log. Tab. Diffs.* taken out concurrently with the logs. themselves. (See Raper, p. 221, 19th Ed.). Their respective values are in each case the same. **Rosser and Johnson—difference in details.**

For ship's run between sights, Johnson corrects the 1st Longitude by applying the difference of longitude *in arc.* Rosser corrects the 1st Apparent Time at Ship by applying the difference of Longitude *in time.*

Johnson divides the difference between the 1st and 2nd Longitudes by the sum or difference of the factors, and the quotient is the error in the Latitude. Rosser divides the difference between the true and computed intervals by the sum or difference of the factors, and the quotient is the error in the Latitude.

To find the Longitude, Johnson corrects the D.R. Longitude, whilst Rosser corrects the D.R. Apparent Time at Ship.

At first glance it might appear that Johnson had no end of advantage in taking out his factors by inspection, but to enable him to do so he must first ascertain the Azimuth, and this to some small extent balances the extra work of taking out and manipulating the *Log. Tab. Diffs.*

The main distinction between these two excellent methods is that, throughout the work, Rosser sticks to *Time,* whilst Johnson sticks to *Arc.* **Main distinction**

Although Rosser's is *very* first-rate, and can be safely recommended, Johnson's—as a simpler and more popular version of the problem—has undoubtedly cut it out. Its greater brevity, freedom from even the *suspicion* of algebra—a regular bugbear to the most of sailors—and fewer rules to remember, are all good points to score. The writer used Rosser's method almost daily for a number of years—it was quite an enjoyment—but eventually abandoned it in favour of Johnson's. Mr. Johnson claims to have been first in the field (1864), but that is a little matter that is scarcely deserving of close consideration here. **Johnson's method more popular**

Lord Kelvin, much impressed with the value of Sumner's method in his own nautical experience, which is not inconsiderable, went to the trouble and expense of publishing a set of tables to facilitate the working, but they have not found general favour, and Johnson's method—taken all round—is hard to beat. The A B C Tables make it impregnable.

In actual practice, the first half of the "Double Altitude" observation is worked out as soon as possible; and it is well to take the second altitude when the bearing has changed about two points, in case a more desirable one should not be obtained later on. It can be kept as a "stand by," and need not be worked out if a better turn up.

Winter better than Summer for Double Altitudes.

As the sun's bearing usually changes more rapidly in high latitudes than in very low ones, the interval between the observations may at such times be correspondingly smaller. This fits in admirably with the sailor's requirements, as it is generally in high latitudes that he happens most to need the aid of this problem.

There are, however, many exceptions which should not be overlooked. The rapidity of azimuthal change depends upon the observer's position with respect to the sun: this can best be seen by an overhaul of Burdwood's and Davis's Tables. Sometimes the change is sufficient with a comparatively short interval, and at others the interval is so long as to render a 'double altitude' practically impossible. This latter will happen when latitude and declination nearly coincide; but even then, if he watches his chances, the wide-awake man may get sights *on different sides of the meridian* which will give a splendid cut with a short interval.

For example, in lat. 10° N., and with declin. 0°, it may happen that owing to a tropical rain-squall, or general cloudiness, the meridian altitude is lost, and "ex-meridians" not to be had with a sufficiently small hour-angle; *But* at 40m. before noon the sun will bear S.E., and at 40m. past noon it will bear S.W.

An irreproachable "Double Altitude."

Here we have an interval of only one hour and twenty minutes with a change in bearing of 90°. Now if the weather permitted sights to be obtained at these times, the Navigator would have good reason to rejoice. The altitude (76°) is not too high, and the 'cut' is perfection.

In this instance it would be next to an impossibility to get a workable double altitude with both sights on the *same* side of the meridian. Reference to Davis will shew that the change of bearing is much too small with *any* interval between sunrise and, say, 10 A.M., and between, say, 2 P.M. and sunset.

Cases such as the one here described are not imaginary; they have a *bonâ fide* existence; are easily found at the proper time, and as easily utilised by those who understand their value.

On board the (s.s.) "*British Crown*," at 8·38 A.M. and 10·38 A.M. on January 17th, 1880, the following observations were made to find the latitude and longitude by Johnson's "Double Altitude" method. Course and distance in the interval, S. 74° W. (true), 25¼ miles, = 7′ diff. of lat. and 32¼′ diff. of long.

Pos. by Acc. { Lat. 40° 23½′ N. / Long. 69° 41′ W. } at 1st. obs.

First observation

	H.	M.	S.
Chronometer	1	25	22
Slow of G.M.T.	+	4	23
G.M.T.	1	29	45
Corrected Equa. of Time	—	10	16
	1	19	29 G.A.T.

☉ . . . . 13° 2½′
Eye 24 feet + 7½
-☉- 13° 10′

110° 47¾′	. . . 0·02925	
40 23¼	. . . 0·11822	
13 10	9·13401	
	9·97018	
164 21	9·25166	
82 10½		
69 00¼		

	H.	M.	S.
Hour Angle	3	19	57 = S. 47¼° E.
A.T.S.	8	40	03
A.T.G.	13	19	29
Long. in Time	4	39	26 =

Long. at 1st obs.	69°	51¼′	W.
Run	+	32¼	W.
Long. (1)	70	23¾	W.
Correction	—	6¼	E.
True Longitude	70°	17½′	West at time of 2nd obs.

Sun's Bearing S. E.
The Contrary N. W.
Therefore apply the correction for the latitude to the North.

Second observation

	H.	M.	S.
Chronometer	3	25	17
Slow of G.M.T.	+	4	23
G.M.T.	3	29	40
Corrected Equa. of Time	—	10	17·5
	3	19	22·5 G.A.T.

☉ . . . . 25° 49′
Eye 24 feet + 9¼
-☉- 25° 58¼

110° 46¼′	0·02920
40 16½	0·11747
25 58¼	8·41550
	9·94806
177 01¼	8·51023
88 30½	
62 32	

Long. (2). .	70°	34¾′	W.
Correction . . .	—	17¼	E.
True Long. . .	70°	17½′	West.

At second observation.

	H.	M.	S.
Hour Angle	1	22	56 = S. 21¼° E.
A.T.S.	10	37	04
A.T.G.	15	19	22·5
Long. in Time	4	42	18·5 =

Long. (2)	70°	34¾	W.
Long. (1)	70	23¾	W.

2·14)11·00(5·14′ Correction for Lat.
10·70
300
214
860
856

Table C.

☉ Bearing S. 47¼° E. — 1′·22 × 5′·14 = 6¼′ corr. for Long. (1).
☉ Bearing S. 21¼° E. — 3′·36 × 5′·14 = 17¼′ „ (2).
Diff. 2′·14

Latitude by Acc. . .	40°	16¼′ N.
Correction	+	5¼
True Latitude . . .	40°	21½′ North at time of second observation.

NOTE.—The accuracy of this position was fully confirmed at noon.

The writer has frequently worked double altitudes by Johnson's method, with a difference of bearing of rather less than a point, and found them come out with wonderful accuracy. If in such cases the "Sumner lines" were drawn on the chart, they would be found *to run together*, and their intersection would be very ill defined indeed. Therefore it is that in many instances calculation is preferable to laying down the lines, &c., on the chart, which latter operation is technically styled "plotting" the work.

Do not tempt Providence

It is not, however, advisable for the inexperienced to take liberties of this kind. The results may turn out very badly, and then the method would be unjustly blamed.

We have now arrived at a stage in this problem when it will be convenient to explain why the first and last pages of Table C are coloured red. First, let it be understood that the colouring is only to be taken into account in connection with 'Double' and 'Simultaneous Altitudes.' When, for example, Table C is used as an Azimuth Table, the colour is devoid of signification.

The 'Danger Signal.'

Red is generally associated with danger. It is so used on a railway, on powder hulks, during target practice, a revolution, and on most other occasions when there is mischief in the wind. Well, when the Azimuths of a Double Altitude are either very small or very large, the red flag is hoisted. In the first of these two events it is to be taken as absolutely *prohibitory*, and in the second as enjoining *caution:* green perhaps would have been better for the last page.

To economise labour in printing, the whole of each page is coloured, but the prohibition in the one case, and the caution in the other, are only intended to apply severely to the first and last 10° of Azimuth.

Hour-Angle and Azimuth.

Just here we will make a little deviation to clear up an ambiguity. In this and other books on the same topic, one constantly meets with the phrase "near the meridian," but being capable of a two-fold interpretation it is apt to breed confusion. To put the reader on his guard, therefore, it will be no harm to remind him that a celestial object can be near the meridian in point of *Time* or *Hour-Angle*, and yet be far from it in Azimuth (see page 466). The converse of this can happen, so when one comes across the expression, it is well to consider in what sense it is used.

Extreme cases serve best for illustration, so let us take one. Latitude of observer = 50° N. Polaris bearing N. 2° E. That is surely near enough to the meridian, but *only in point of Azimuth*, for *in point of Time* it is then six hours from the meridian

Take another case. Latitude 20° N., Declin. 20° N. Time from noon, 5 min. This also is surely near enough to the meridian, but *only in point of Time*, for *in Azimuth* it is 90° from the meridian, or on the Prime Vertical. This matter being settled, we will return to 'Double Altitudes.'

Compromises are common.

By now the reader must be familiar with the precept that observations for *Latitude* are better in proportion to the *smallness of their Azimuth*, and that observations for *Longitude* or *Time* are better in proportion to the *largeness of their Azimuth.* Those for Latitude are at their best when the Azimuth is 0°, and those for Longitude when the Azimuth is 90°. 'Double Altitudes' are a combination designed to give both Latitude and Longitude, and, being a sort of compromise, it will be advisable to avoid either extreme of the gamut. The mere fact of combination does not necessarily free them from the drawbacks to which they would be subject if acting singly and independently.

Let us take an altitude with a small Azimuth and see what happens. Turn to Table C, Lat. 60°, and Az. 4°. In this case the error in the hour-angle arising from the trifling error of 1′ in the Latitude is so great, *and varies so rapidly*, that no dependence could be placed in results obtained from such *fluctuating* conditions, and especially will this be so in high Latitudes.

Action and re-action.

Perhaps this would be plainer if put in another way.—It must be apparent that the position depends entirely upon the correctness of the values furnished by Table C, whether expressed in arc or time does not signify. If these are wrong, the whole panjandrum goes wrong. Now, to take out these quantities with sufficient correctness, the Azimuth—*when small*—must be accurately known; even half a degree will cause an immense jump in the value of the quantity, but unfortunately the Azimuth itself is derived from the D.R. App. Time at Ship, and this may be seriously in error. Therefore, unless by a fluke the Latitude worked with should happen to be correct, the tabular quantities will be wrong and must give a wrong result.

On the other hand, the most casual inspection of Table C will shew that, with azimuths larger than 12° or 15°, the values alter comparatively slowly; consequently, approximate working data will give the azimuth sufficiently near the truth, and this in turn will give sufficiently correct values from Table C. These elements act and re-act upon each other. But even in this last event, should the ascertained Latitude differ widely from the Latitude worked with—say 20′ or so—it would be prudent to repeat the calculation, using, of course, the amended Latitude. To do so would not be such a *very* big job, as fully half of the original work would still hold good.

In practice, however, the navigator must take what he gets and be thankful. He cannot always control the phenomena of nature, but, like a good admiral with certain forces at his disposal, he should know how best to turn them to account. Therefore, when it happens that one observation has a small azimuth, and the other a large one, it would be better to put 'Double Altitudes' on one side, and look for some other means of finding the ship's position. It at once suggests itself that the sight near the Prime Vertical will give the correct *Time*, even though the D.R. Latitude be considerably in error; and with this correct time it is easy to find the correct *Latitude* from the other sight *by treating it as an Ex-Meridian.*

Never say die.

If there be any doubt, repeat the work with the amended Latitude, and, if the sights were good, a close approximation will follow. This disposes of the first page of Table C, and with the reader's permission we will let the other stand over for the present. It will keep.

Two ways of looking at the principle.

Thus far the active *principle* of the problem has been put before the reader in *graphic form* only, namely, by Sumner's method of projection on a Mercator's chart; but it will materially assist to a more complete understanding if the principle be considered from an entirely different standpoint. In reality the same principle permeates all Double-Altitude methods, but certain of its phases are more discernible in some lights than in others. The point of view now to be dealt with is that of the *Elapsed Time* between sights. Time, as we know, plays a prominent part in navigation.

In the September number of the *Nautical Magazine* for 1892, there was a rattling paper on the *Double Chronometer* problem by Captain Philip R. H. Parker, R.N., which, from its thorough-going salt-water style, was appreciated by the majority of seamen.

The chief merit of the paper lies in the clever manner in which the sub-current of principle—*freed from mathematical trammels*—is dragged out of the depths, and made to shew itself in the broad light of day.

Captain Parker goes straight to the goal; there is no wavering, no side issues to obscure the main fact; the line of argument is simplicity itself, and the conclusions cannot be disputed.

Further, there are no intricate rules to remember, the 'why and the wherefore' of everything are "as plain as a pikestaff." As Captain Parker himself says, "The rule unfolds itself as it goes along." "True blue for ever."

This much in favour—and it is a good deal, but there is, unfortunately, something to be said on the other side. As compared with rival methods, the working is undoubtedly roundabout, inasmuch as to find the error in the hour-angles due to an error of 1′ in the latitude, a very considerable portion of the work has to be repeated: that is all that can be said against the *method.* It is not much to some men, whilst to others it is an effectual bar. As a clear and popular exposition of the *Principle*—taking Time for its basis—Captain Parker's paper stands unrivalled, and is a most welcome addition to the literature of the subject. It gives the writer much pleasure to reproduce it in these pages, and to this Captain Parker and the then Editor of the "*Nautical*" most kindly gave their consent. The reader can now judge for himself. Parker's method unmatched in clearness.

A NEW VERSION OF AN OLD PROBLEM IN NAVIGATION.

"There is a problem in Navigation which has been in use for a long time, and is known by various names, such as "the method by trial and error, the approximate double altitude, and the double chronometer." It seems to have been first proposed by Lalande, a French astronomer, in 1764. As the method by trial and error it was much used by our fathers between 1780 and 1820. Lynn (1830) gives it. Raper gives it as the approximate double altitude. About 1845, Pagel, a French naval officer, proposed it for latitude and longitude as the double chronometer. Johnson gives a modification of it, and Captain Martin, in his recent work, gives both Pagel's and Johnson's forms of it. Up to Pagel's time it was a latitude problem solely, but since that it has been used to fix the position both in latitude and longitude. It depends on the following fact:—

If two altitudes of the sun or other heavenly body are taken with an interval between them, and if the apparent time is calculated from each altitude, then the interval between these apparent times ought to be the same as the interval shown by the chronometer (corrected for run if necessary), and it *will always be so*, provided the true latitude has been used in calculating the observations.* Hence, if the interval (from the chronometer), and the computed interval (from the sights) do not agree, we know the latitude used is not the true one, and we must look *there* for the error and correct it. It follows, too, in these days of accurate chronometers, that if we fix the latitude we can get the longitude also, and so determine the ship's position fully.

The rules for working this problem at present seem to me somewhat clumsy,

* Captain Parker purposely omits reference to the effects of errors of altitude, as being foreign to the purpose of his paper, but the navigator must bear them in mind. The writer will deal with them further on.—*Lecky.*

and likely to frighten off some of our weaker brethren (in mathematics) from what is really a most simple and useful method, one which, moreover, possesses the merit of affording a check on its own errors. It is possible to make the problem "prove," as we used to say at school long ago, and this is surely a great advantage. The rules at present given (Raper, Ed. 1857, p. 247, and Martin, double chronometer chapter) are many and complicated. They are founded on the differential equation

$$\frac{\Delta \text{ Hour-angle}}{\Delta \text{ Co-latitude}} = -\frac{\text{Cot. Az.}}{\text{Cos. Lat.}}$$

or as it becomes for computation :—

Sin. Diff. Hour Angle = − Sin. 1′, Cot. Az. Sec. Lat. (a).

Now since this is a differential equation, the negative sign not only carries its own algebraical power, but also signifies that the hour-angle and co-latitude vary in contrary directions, *i.e.*, as one increases the other decreases, and *vice versâ*. Hence the complicated system of rules and signs to render easy a bit of the higher mathematics to those unacquainted with them. These rules in Raper take up two pages, and in Martin about a page and a half.

I would therefore propose a new method, which I believe to be simpler and more logical. The chronometer interval, corrected (if necessary) for the run, is the true difference of apparent times of sights.* Make this, then, the standard of comparison, and if the difference of the computed apparent times does not agree with it, it is clear that there is an error in the latitudes used. To ascertain this, work each sight with a latitude one mile North or South (as you may choose) of the first latitudes used. The difference between these apparent times shows the variation caused by putting the latitude one mile either way, and will also show which way the interval must be corrected. To correct the latitude is then only a proportion sum. The *computed* interval differs by so much from the *true* interval, and the effect of one mile North or South in latitude is to alter the computed interval by so much. The one quantity divided by the other gives the miles and fractions of a mile, the latitudes first used were in error. Knowing the true latitudes, the longitudes are found in the usual way.

There is in all this no limitation, and no necessity to consider cases, or whether the sun is one side or the other of the prime vertical or meridian. The rule unfolds itself as it goes along. Two quantities ought to be equal, and they are found not to be so. Hence there is a reason, and the reason shows itself on the figures, viz., that the latitude used is too far North or too far South. But the figures also show how much one mile of latitude affects the first-named quantities, and in what direction The rest is a proportion sum. Can anything be much more simple?

The method of correcting the time-interval for run has not been in use before, and is adopted in order to get a true standard with which to compare the computed quantities.† Such a standard is given by the true difference of apparent times, which may be obtained from the chronometer interval cor-

* In practice it may be taken as such without material error when the interval is short, but it is not so in fact. The *change* in the equation of time must be allowed for: the maximum is about 1s·25 per hour.—*Lecky.*

† Captain Parker of course means the interval by *chronometer*. In other methods it is the *computed* interval which is corrected for the ship's run.—*Lecky.*

rected for the change of longitude due to the ship's run. If a ship is stationary, the true difference in apparent time between any two observations is the same as the interval of time shown by the chronometer. But in actual practice at sea there will always be a change of position between the sights, and it is a familiar fact to seamen that this change of position causes a gain or a loss of time. Hence the necessity of correcting the chronometer interval for the difference of longitude due to the run. Therefore every care should be taken to estimate the run accurately, as an error here may lead to a large error in the ship's position. It is usual now to steer the ship to the nearest degree, and I would recommend that the log be read as each sight is taken. This can be done with most logs without hauling in. I do not think I need trouble to give the proof of a problem sailors have been using since 1770. Hence I will only give the rules :—

1. At any convenient time take the altitude of any heavenly body, and with the D.R. latitude determine the ship apparent time. Determine also the ship apparent time due to a latitude one mile North or South, as you may think fit.

2. Note very carefully the course and distance run by the ship up to a second convenient time, and find thence the Diff. Lat. and Diff. Long. made good. Turn the Diff. Long. into time, and correct the D.R. latitude to the second convenient time.

3. At the second convenient time take another altitude of the same (or a different) heavenly body, and thence determine the ship apparent time, and also the apparent time due to a latitude one mile North or South, *in the same way as before* under precept 1.

4. Take the difference of the chronometer times of observation, and to it apply the difference of longitude in time, adding if the run was East, subtracting if the run was West. This is the true difference of apparent times, or, as we shall call it, the "true interval."

5. Take the difference of the apparent times given by the D.R. latitude and the latitude obtained from it by applying the correction for run. Take also the difference of the apparent times given by the latitudes one mile North or South of the above, as it may have been worked under precepts 1 and 3. These are the computed differences of apparent times, and we shall call them "computed intervals." The difference of these computed intervals is the change in interval due to one mile of latitude North or South, as the case may have been ; and it will be seen at once whether this change tends to increase or decrease the interval.

6. To correct the latitude is now a simple proportion sum. If either of the *computed* intervals agree with the *true* interval, then that set of latitudes are the correct ones at the first and second observations. If they do not, then decide which of the computed intervals it is desired to correct. That due to the D.R. latitude and the run is usually the more convenient. Take the difference between the true interval and the chosen computed interval. This is the whole quantity to be corrected. Divide it by the change of interval obtained under precept 5. The result is the miles and fractions of a mile the latitudes worked with are in error.

To check the correction, take the difference between the apparent times found at the first observation, note very carefully how it varies. This will be the correction in apparent time due to one mile of latitude. Multiply it by the correction in latitude, and apply with the proper sign. That will give the correct apparent time at the first observation. Repeat the process for the second observation. The interval between these corrected apparent times ought to be the same as the true interval. If it is not, there is something wrong with the work.

Note.—The corrected apparent times are here obtained by proportion. This will not be true, when—

(*a*) There is any great correction in latitude, say over 20′.

(*b*) The difference in apparent time due to one mile of latitude is large, say over 20^s, as will be the case near the meridian.

In both these cases the apparent times should be re-calculated with the corrected latitudes, and corrected again, if necessary, till the true and computed intervals correspond.* I hope the method will be found serviceable, and I append some examples:—

On the 25th January, 1891, on board R.M.S. *Orizaba*, in lat. by account 8° 50′ N., the sun's zenith distance (W. of mer.) was 27° 43′ 45″ at $19^h\ 32^m\ 33^s$ G.M.T. The declination was 19° 0′ 30″ S., and the Eq. T. $12^m\ 30^s$ + to App. Time.

With these elements the Apparent Time will be found to be $0^h\ 10^m\ 9^s$ P.M. for Lat. 8° 50′ N., and $0^h\ 10^m\ 53^s$ P.M. for Lat. 8° 51′ N.

The ship then ran S. 75° E. 18 miles, and a second observation showed the zenith distance to be 34° 41′ 15″ at $20^h\ 52^m\ 22^s$ G.M.T. The corresponding declination and Eq. T. were 18° 59′ 30″ S. and $12^m\ 31^s$ +.

This second observation gives $1^h\ 24^m\ 28^s$ P.M. App. Time with Lat. 8° 45′ 15″ N., and $1^h\ 24^m\ 22^s$ P.M. App. Time with Lat. 8° 46′ 15″ N.

The diff. long. in time due to the run will be found to be $1^m\ 11^s$, and the run is Eastward.

We have therefore—

$20^h\ 52^m\ 22^s$ = Latest Chronometer Time.
19 32 33 = First Chronometer Time.

1 19 49 = Chronometer Interval.
+ 1 11 = Correction for run East.

$1^h\ 21^m\ 00^s$ = True Interval.

This true interval is the standard of comparison to which we refer our other times.

We have further

$1^h\ 24^m\ 28^s$ P.M. = Second Apparent Time } Due to Lat. 8° 50′ N. and the run.
0 10 9 P.M. = First Apparent Time }

$1^h\ 14^m\ 19^s$ = Computed interval due to D.R. lat.

Also we have

$1^h\ 24^m\ 22^s$ P.M. – Second Apparent Time } Due to Lat. 8° 51′ N. and the run.
0 10 53 P.M. = First Apparent Time }

$1^h\ 13^m\ 29^s$ = Computed interval due to a latitude one mile *North* of the D.R. lat.

* Rather a big order to a man in a hurry. *Moral:* Don't use the method of "Double Altitudes" where it is obviously inapplicable.—*Lecky.*

From this it is quite plain that the interval due either to the D.R. lat., or a latitude one mile *North* of that, is *too small.* Further, that putting the latitude to the Northward *decreases* the interval at the rate of ($1^h\ 14^m\ 19^s$ − $1^h\ 13^m\ 29^s$) = 50^s per mile. It is therefore evident that 8° 50′ N. is farther North than the true latitude, which must be put to the Southward.

To ascertain how much, we have—

$1^h\ 21^m\ 00^s$ = True Interval.
1 14 19 = Interval due to 8° 50′ N.

$6^m\ 41^s$
60

401 seconds = Error in computed Interval.

Now, since the Interval, as we have seen above, alters 50^s for each mile of latitude, it is plain that a correction of 8′ South will make the latitude right. Hence the true latitude is 8° 50′ N. − 8′ = 8° 42′ N.

To see that this is accurate, we will correct the computed intervals. To do this we have—

$0^h\ 10^m\ 53^s$ P.M. = Apparent Time at 1st obsn. due to 8° 51′ N.
0 10 9 P.M. = Apparent Time at 1st obsn. due to 8° 50′ N.

+ 44^s = Diff. due to one mile North.
Hence − 44^s = Diff. due to one mile South.
∴ − $5^m\ 52^s$ = Diff. due to eight miles South.
i.e. $10^m\ 9^s$ − $5^m\ 52^s$ = $4^m\ 17^s$ = App. Time due to 8° 42′ N.

Similarly—

$1^h\ 24^m\ 28^s$ P.M. = Apparent Time at 2nd obsn. due to 8° 45′ 15″ N.
1 24 22 P.M. = Apparent Time at 2nd obsn. due to 8° 46′ 15″ N.

− 6^s = Diff. due to one mile North.
∴ + 6 = Diff. due to one mile South.
∴ + 48 = Diff. due to eight miles South.

Hence $1^h\ 24^m\ 28^s$ + 48^s = $1^h\ 25^m\ 16^s$ = Apparent Time due to 8° 37′ 15″ N. which is the latitude by D.R. of the second observation if 8° 42′ N. is the latitude of the first.

Thus for the corrected interval we get—

$1^h\ 25^m\ 16^s$ P.M. = Computed App. Time of 2nd observation.
0 4 17 P.M. = Computed App. Time of 1st observation.

$1^h\ 20^m\ 59^s$ = Computed Interval of App. Times, which is only 1^s from the True Interval of $1^h\ 21^m\ 00^s$. This verifies the latitude.

To get the longitudes we have—

	For 1st Observation.		For 2nd Observation
App. Time at Ship ...	$0^h\ 4^m\ 17^s$	...	$1^h\ 25^m\ 16^s$
Eq. Time	+ 12 30	...	+ 12 31
Mean Time at Ship ...	24 16 47	...	25 37 47
Mean Time at Greenwich	19 32 33	...	20 52 22
Long. E....	$4^h\ 44^m\ 14^s$	...	$4^h\ 45^m\ 25^s$
	= 71° 3′ 30″		= 71° 21′ 15′

The run gives 17′ 45″ Diff. Long., and so the two longitudes agree.

Also allowing a run of S. 75° E. 1 mile, from noon to 1st observation, we get for the noon position, deduced from these observations, 8° 42′ 15″ N., and 71° 2′ 30″ E. The noon position by meridian altitude, and A.M. chronometer sights was 8° 42′ N., 71° 3′ E.

It will be noticed that this is not what would be generally considered as a favourable case. Both sights are P.M., and the first sight is not five minutes from the meridian. But (and it is one of the advantages of the method) there do not seem to be any limitations to this problem. But where there is a large difference in Apparent Time due to an alteration of one mile in latitude (such as 44ˢ here), it is not safe to trust to the computation of the Apparent Times by proportion simply. It is better to recalculate them rigidly, and this should also be done if there is a very large correction (over 20 miles) to be made for latitude.

Doing this here, and taking the trouble to work to the nearest second, we find that 8° 42′ 6″ N. is the latitude at the first observation, and that the Apparent Times are $0^h\ 4^m\ 10^s$ and $1^h\ 25^m\ 10{\cdot}5^s$. These give the computed interval, $1^h\ 21^m\ 00{\cdot}5^s$, which agrees with the true interval, and they give for longitudes 71° 1′ 45″ E., and 71° 19′ 45″ E. respectively.

EXAMPLE II.

On Monday, 28th Dec., 1891, at my house in Hobart, Tasmania, I obtained the following sights. The time was taken by a Waltham pocket watch which was known to keep mean time.

At $7^h\ 23^m\ 8^s$ A.M. the zenith distance was 58° 9′ 00″, the declination being 23° 19′ 30″ S.

And at $8^h\ 39^m\ 48^s$ A.M. the zenith distance was 44° 9′ 45″, the declination being 23° 19′ 15″ S.

I chose to work with Lat. 42° S., as an experiment, though I knew this was more than 50′ out, the true Lat. being 42° 53′ 30″ S.

With Lat. 42° S. the Apparent Times were $19^h\ 30^m\ 35{\cdot}1^s$ for 1st observation, and $20^h\ 46^m\ 7{\cdot}5^s$ for 2nd observation.

With Lat. 41° 59′ S., the times were $19^h\ 30^m\ 35{\cdot}5^s$ and $20^h\ 46^m\ 6{\cdot}6^s$ respectively.

Hence (as there is no run) we have—

8^h	39^m	48^s	=	Latest Chronometer Time.
7	23	8	=	First Chronometer Time.
1^H	16^M	40^s	=	True Interval.

Also—

20^h	46^m	$7{\cdot}5^s$	=	Second App. Time due to 42° S. Lat.
19	30	35·1	=	First App. Time due to 42° S. Lat.
1^H	15^M	$32{\cdot}4^s$	=	Computed Interval due to 42° S. Lat.

And—

20^h	46^m	$6{\cdot}6^s$	=	Second App. Time due to 41° 59′ S.
19	30	35·5	=	First App. Time due to 41° 59′ S.
1^H	15^M	$31{\cdot}1^s$	=	Computed Interval due to 41° 59′ S.

Hence we see—

1st. That the Computed Interval is too small, and must be increased.

2nd. That putting the latitude to the Northward makes it still smaller, and therefore the correction is South.

As to the amount of correction we have—

$1^h\ 15^m\ 32{\cdot}4^s$ = Computed Interval due to 42° S.
$1\ \ 15\ \ 31{\cdot}1$ = Computed Interval due to 41° 59′ S.

$-\ 1{\cdot}3^s$ = Correction for One Mile North.

Also we have—

$1^h\ 16^m\ 40^s$ = True Interval.
$1\ \ 15\ \ 32{\cdot}4$ = Computed Interval due to Lat. 42° S.

$1^m\ 7{\cdot}6^s$ = Error in Computed Interval.
60

$1{\cdot}3)67^s{\cdot}6(52'$
65

$2{\cdot}6$
$2{\cdot}6$

Hence there is an error of 52′ in the latitude, to be applied to the Southward.

This will give 42° 52′ S. as the true Lat., and $0{\cdot}4^s$ − as the correction for one minute of Lat. to be applied to the first sight; and $0{\cdot}9^s$ + as the correction to be applied to the second.

This gives—

$20^h\ 46^m\ 54{\cdot}3^s$ As the Computed App. Time at 2nd observation.
$19\ \ 30\ \ 14{\cdot}3$ As the Computed App. Time at 1st observation.

$1^h\ 16^m\ 40^s$ Computed Interval.
Which confirms the latitude.

But as a correction of 52′, even near the prime vertical, is a large amount, it will be better to re-work these sights with Lat. 42° 52′ S. If we do so, we shall find the Lat. to be 42° 52′ 30″ S., or one mile from the true Lat.

The Long. was not obtained here, as the watch was only a pocket one, and no chronometer was available, but I have no doubt these sights would give an excellent Long. if the G.M.T. had been known.

To show the value of close working, I may mention that these sights worked to the nearest second give 42° 53′ 10″ S., which is a little more than a quarter of a mile only from the truth.*

The last example I shall give is taken from Captain Martin's recent work on Navigation. I give it to illustrate the difference in the way of working between that given here and that given by Captain Martin or by Pagel, for both methods are found in the book. I do not think it right to ask the Editor for space to give the methods side by side, as anyone interested in these matters will most likely have Martin's book at his disposal, so I simply give my own working :—

* All very well on shore with an artificial horizon, &c., but in sea practice, working to seconds is an absurdity.—*Lecky.*

On 25th April, at 7.30 A.M., lat. D.R. 49° 20′ N., long. D.R. 5° 40′ W., the following observation was taken :—

Chron.—8^h 1^m 50^s ⊙ 24° 49′ 20″. True bearing, S. 82° E The ship then ran N.E. by E. ½ E. 12 miles – variation 22° W., deviation 21° E., till 9.40 A.M., when

Chron.—10^h 10^m 22^s ⊙ 43° 52′ 10″. True bearing, S. 51° E.

On 20th April Chronometer was slow on G.M.T. 11^h 51^m 2^s, and the rate was $5·6^s$ losing. I. E. + 2′ 10″. Dip 20 ft.

Corrected declination, 1st observation, 13° 21′ 30″ N. Eq. T., 2^m 11^s – from App. Time.

Corrected declination, 2nd observation, 13° 23′ 30″ N. Eq. T., 2^m 12^s – from App. Time.

The first observation worked with 49° 20′ N. and 49° 21′ N. gives 19^h 31^m $57·7^s$, and 19^h 31^m $58·6^s$ for the Apparent Times.

The run gives 5′ 45″ N. difference latitude, and 16′ E. difference longitude.

The second observation worked with 49° 25′ 45″ N. and 49° 26′ 45″ N gives 21^h 40^m $56·8^s$, and 21^h 41^m $1·9^s$ for the apparent times.

The chronometer times, corrected for error and rate, are :—

For 1st observation, 19^h 53^m $19·9^s$ }
For 2nd observation, 22^h 1^m $51·5^s$ } Run, 1′ 4″ East.

Hence we have :—

True interval, 2^h 9^m $35·6^s$.

Computed interval (due to 49° 20′ N.), 2^h 8^m $59·1^s$.

Computed interval (due to 49° 21′ N.), 2^h 9^m $3·3^s$.

Hence the computed interval is too small, and must be altered to the Northward, since one mile North in latitude increases it by $4·2^s$.

Now, the difference between the true interval and the computed interval due to 49° 20′ N. latitude, is $36·5^s$, and this divided by $4·2^s$ gives 8·7′ as the correction for latitude.

Hence the latitude at 1st observation is 49° 28′ 45″ N.

And the latitude at 2nd observation is 49° 34′ 30″ N.

To confirm this, if we make the proportion, we find the interval to be 2^h 9^m $35·8^s$, and if we calculate it rigidly it is 2^h 9^m $35·3^s$.

The corresponding longitudes are 5° 51′ 15″ W., and 5° 35′ 30″ W."

Hills look blue in the distance.

The problem as thus presented by Captain Parker is confessedly a captivating one, and it is made more so by the statement that there are no restrictions as to the time at which the observations may be made; but as to this the writer feels called upon to sound a note of warning. "All is not gold that glitters." It is true the statement is subsequently qualified, but the reader in his enthusiasm may lose sight of the qualification and come to grief, as we shall presently see.

Captain Parker's position at noon deduced from working with Lat. by D.R. 8° 50′ N. is

Latitude 8° 42¼′ N.
Longitude 71° 2½′ E

But by re-calculating *rigidly*, and *working to the nearest second of arc*, he gets finally

Latitude 8° 42½′ N.
Longitude 71° 1¾′ E.

Now all this looks very pretty and delightfully exact, especially as it is stated to agree with the orthodox meridian altitude, &c., but as a measure of the capabilities of the *problem* it is highly delusive, and in the hands of some people might be dangerously misleading.

A simple test. Let us put it to the test—and a simple one. Suppose that instead of 8° 50′ N. the latitude by D.R. had been 8° 34′ N., or as much to the southward of the *true* position as the other is to the northward: then using this more southerly latitude we get a widely different result, namely, for noon—

Latitude 8° 46¾′ N.
Longitude 70° 56½′ E.

Now these two positions (worked with latitudes only 8′ on either side of the true one) cannot *both* be right, since the approx. true position by "Double Altitude" appears to be

Latitude 8° 42½′ N.
Longitude 71° 1′ E.

So that the more northerly assumed latitude gives the better result. But *why* should there be any difference whatever if the method be immaculate? Without entering upon details, with which the reader should be conversant by this time, the plain unvarnished fact is, let the particular *method* be what it may—Parker's, Rosser's, Johnson's, or any other—a "Double Altitude" worked with an observation so very near the meridian (S. 2¼° W.) is quite untrustworthy, and to employ the *problem* at such unreasonable times is to put it to a wrong use and bring it into discredit.

A square peg in a round hole.

Had the Latitude been a high one—say 50°—the discrepancies would have been still more glaring.

To get even an *approximate* result in D. A. observations near the meridian, the Declination must be reduced to the G.M.T. by 'second differences'; the Altitude must in itself be irreproachable, and its various corrections taken out separately; the general working must be to 0″·5, and the greatest care observed in taking out the log. cosine of the half-sum. The run also must be mathematically exact, and altogether,—THE THING IS IMPRACTICABLE.

If the navigator had no other resources, he might well be pitied, but it has been demonstrated that there is no need to treat "Double Altitudes" in such heroic fashion. Captain Parker's example is of course merely intended to elucidate the principle of his method, and not to be taken as recommending its use under prohibitive conditions. He is too good a mathematician to wish otherwise.

As the article stands in the *Naut. Mag.* there is an obvious slip in the application of the small latitude-correction for run between first sight and noon; it has been corrected in these pages. Both Polar Distances, the first Equation of Time, and the correction of the true interval, though slightly in error, have a not inconsiderable effect on the result. This is only mentioned to put in strong relief the unwisdom of such experiments.

Principal use of Parker's method.

As a *teaching* method, this of Captain Parker's is invaluable, the reason of each step is so manifest; but as an every-day method where brevity is an essential, it is surpassed both by Rosser and Johnson; nor is its power of solution any greater, for it fails where they all fail—*in the small azimuths.*

Up to this point the "Double Altitude" has been treated on the assumption that the only element in error is the *Latitude*, but sufficient has been said in previous chapters to accentuate the possibility—nay, probability—of the *Altitude* being generally more or less inaccurate. Now, *no* problem can be expected to give a correct result when the altitude is incorrect; but the effect of any such error is much more felt in some cases than in others.

Altitude errors.

For instance, the error in the noon latitude varies *directly* as the error in the Meridian Altitude: whatever the one, so will the other be. The same may *almost* be said of the longitude determined from an observation on the Prime Vertical. In both cases an error in the altitude will produce its *least* effect: these, then, are the most desirable times for their respective purposes.

But let us take something intermediate. For example, in Lat. 50° N. (the parallel of Scilly), let it be required to find the Longitude from a sight taken when the sun's Azimuth was 9°. Reference to Table D shews that the error would be 10′ = 40s. of time for each 1′ of error in the *Altitude*, and as, in roughish weather, it would not be unreasonable to assume an error in Altitude of even double this amount, it follows that—*quite apart from* what might be due to wrong *Latitude*—the Longitude might easily be vitiated to the extent of 20′ = 1m. 20s. In fact, the two errors would be hopelessly mixed up.

It has been demonstrated, quite regardless of the particular method employed, that the "Double Altitude" problem hinges upon the result of a comparison of the *true* and *computed* intervals. If it could be *ensured* that a discrepancy was due wholly and solely to error in the assumed *Latitude*, all would be well; but, unfortunately, this is impossible, and therefore conditions must be avoided where the effect of even a small error in *Altitude* would be exaggerated immensely in the result.

Saddle the right horse.

In the *Orizaba* example, the sights need to have been exceptionally good, the instrument first class, the observer a practised hand, the horizon well defined, height of eye accurately known, and the atmospheric conditions normal. The first sight was actually taken little more than 4m. from noon, at which time the trifling error in *altitude* of $0\frac{1}{2}'$ would cause an error in the deduced time of nearly 1m., which of course would mean ruination to the measure of the computed interval.

Now, what has been said about the effect of errors in altitude applies—but in less degree—to the last page of Table C.

In *ordinary* sights for Longitude this is the one within which it would be most advantageous that the observations should fall. Any error in *Altitude* would then produce its *least* effect, and we have seen that with azimuth 90° an error in the *Latitude* actually produces *no effect whatever*. It is just this latter feature that cripples the D.A. problem should *both* sights be taken within the limits of the last page. To get a satisfactory result it would be necessary that the altitudes should be above suspicion.

Altitude more important than latitude.

Let us suppose the following case.—In Lat. 50° N. two sights are taken, the first with a bearing of N. 81° E., and the second with a bearing of S. 81° E., both in the last page of Table C. The difference in bearing is 18°, or a point and a half, and, *so long as the altitudes can be relied upon*, the resulting position would be a fairly good one. It is true the sum of the tabular quantities is small ($0'\cdot49$), but owing to the differential character of the problem, the difference in the two longitudes will be small also, and, as one has to be divided by the other, there is no objection on this score. But taking the altitudes as doubtful, Table D shews that for each $1'$ of error the Longitude will be falsified to the extent of rather better than $1\frac{1}{2}'$, whereas a corresponding error in the Latitude will only produce one-sixth of this effect, and accordingly would be swamped. In other words, any difference in the longitudes might be wrongly attributed to error in the assumed *Latitude*, when such difference was *really* produced by an error in the *Altitude*. This can hardly be considered satisfactory. The effect is well shewn by construction.

Though Captain Parker's paper does not deal with the effect of altitude errors, he indirectly cautions against them when he says that an error in the run "may lead to a large error in the ship's position." The reader will see that this may fairly be translated into an error of altitude.

It is laid down as axiomatic in "Double Altitudes" that the best results will mostly be obtained when the change in the bearings exceeds the lesser bearing, the climax being arrived at when the change is 90°. According to this, sights bearing N. 81° E. and S. 81° E. would be unfavourable.

Where the conditions vary much, it is not possible to frame a rule to meet all cases; what may be right and proper under some circumstances may not be so with others. Much will depend upon the *nature* of the problem to be solved, much upon the *mode* of solution, and much upon the reliability of the *data* employed. The navigator must trust to judgment. Judgment is begotten of knowledge, and if this is only skin-deep he will be sure to blunder sooner or later. At sea, blunders are dangerous, hence the necessity for thoroughly understanding the *principle* upon which each problem turns. Any small boy can do the mechanical addition and subtraction.

Coloured pages of C. The colouring of last page of C is therefore not to be taken as forbidding its use, but to remind that *there may be times* when its use would be objectionable. Here is a case where it would give excellent results, other things being equal.

Lat. 50° N., Declin. 21° N. First alt. at 0^h 43^m P.M. bearing S. 20° W., second alt. at 5^h 39^m P.M. bearing N. 80° W. But the interval would be nearly 5 hrs., and, in view of current, &c., the run in that time could hardly be expected to be free from error. On the other hand, as will be shewn in the next chapter, "Simultaneous Altitudes" on the bearings named would be magnificent.

"Fixing" in mid-ocean. However clever he may be, the practical man knows full well the difficulty on the open ocean of locating a ship with certainty within the space of a square mile. It is not much to look at on the chart, but it means a lot where rocks and shoals are generously distributed. To accomplish this feat—even under most favourable circumstances—requires an accurate eye, tip-top instruments, and, above all, a knowledge of how to use them so as to secure the very best results.

Various hidden errors militate against strictly accurate work, and principal among these may be ranked errors in the G.M.T., and errors in the Altitude. It has been shewn in Chapter III.

how the latter may be made to neutralise each other, and in Chapter XIV. the subject will be further developed.

When the navigator is unable to pick and choose at discretion, and has to fall back upon chance sights, he must lay himself out to estimate the error of altitude at the time of observation by due consideration of the atmosphere and water as affecting refraction; and of the motion of the ship and roughness of the sea as affecting the dip of the horizon. The various instrumental errors are under control and may be checked, the personal error may or may not be known (it should be), but the accidental errors can only be estimated, and to do so successfully, requires EXPERIENCE.

The wary navigator will therefore always allow a wholesome margin of possible error, and avoid cutting things too fine on critical occasions. When used within proper limits—and these are plenty wide enough—the *Double Chronometer* problem is one of the most convenient of all the approximate methods of defining a ship's position. It is only beaten by its twin brother "Simultaneous Altitudes." The word approximate is used advisedly, for if the ship is to go safely, he who commands her must recognise, however unpalatable, that no astronomical method for use afloat is more than approximate. *The degree of approximation attainable depends upon the knowledge and skill of the individual.*

Double Altitudes applicable to all Heavenly Bodies.

If the reader be desirous of going very thoroughly into the fundamental principles of Double Altitudes, Double Chronometers, Simultaneous Altitudes, and similar items, which are but Sumner in motley garb, he should carefully study an excellent booklet of 24 pages, by Captain (now Admiral) H. E. Purey-Cust, R.N., entitled *Sumner's Method.* The problem is there handled in a masterly style, and in language suitable to the indifferent mathematical training of the merchant seaman.

What has been stated in this and the previous chapter, with regard to "Circles of Equal Altitude," "Sumner lines," and "Double altitudes" generally, is equally applicable to Sun, Moon, Planet, or fixed Star—the principle is the same; but as there can be no possible reason on a clear night to *wait* for a "Double altitude" of a star, when the Heavens are full of objects in the most suitable positions for simultaneous *Astronomical Cross-bearings*, it is proposed to devote the next chapter to the method of finding the latitude and longitude by *simultaneous* altitudes of two or more fixed stars.

Simultaneous Altitudes of Stars.

CHAPTER XIII.

SIMULTANEOUS ALTITUDES.

The problem of the "Circle of Equal Altitude" may be extended to any celestial body. The pole of the circle will always be the place the longitude of which is the Greenwich hour-angle of the object (reckoned westward), and the latitude of which is the same as the declination of the object. If the object be the sun, the position of the pole of the circle is termed the *sub-solar* point; but if the object be a star it is termed the *sub-stellar* point, these being the places at which the sun or star is in the zenith at the moment.

How to ascertain position of Star at any given instant.

The Greenwich hour-angle of a star is as easily obtained as that of the sun; since, if there is extra work in one part, it is made up for by the fact that we take out at sight the Declination and Right Ascension without having to make any corrections. Thus:—

Over what places on the earth's surface were the stars Sirius and Benetnasch vertical at 7h. 27m. 46s. G.M.T., on February 21st, 1880?

	✱ Sirius.		✱ Benetnasch.	
	H. M. S.			
Greenwich mean time	7 27 46			
Sidereal time at G.M. noon	22 3 10·9			
Acceleration for G.M.T.	+ 1 13·5		H. M. S.	
Sidereal time at Greenwich	29 32 10·4		20 32 10·4	
✱'s Right Ascension	6 39 53·7		13 42 51·2	
Longitude in time	22 52 16·7	W.	15 49 19·2	W.
	24		24	
Longitude in time	1 7 43·3	E.	8 10 40·8	E.
	° ′ ″		° ′ ″	
Longitude of sub-stellar point	16 55 50	East	122 40 12	East.
✱'s Declination " "	16 33 20	South	49 54 18	North.

Sub-stellar point.

Note:—

It does not affect the question, but there is no harm in stating how these two stars bear from each other—

From Sirius to Benetnasch	N. 42¼° E.	Great Circle.
From Benetnasch to Sirius	N. 89° W.	Great Circle.
Angular Distance 112¾°.		

Having thus found the centres of the circles, their size at any given moment will depend entirely upon the altitudes obtained at the place of the observer. In the case before us—to which this is the introduction—the circles are very large, as the observed altitudes happen to be both small.

The true altitude of Sirius is 15° 56½′, and that of Benetnasch 16° 24½′; and the circles intersect in Latitude 51° 1′ N., Longitude 17° 43′ W. The "Sumner lines" cut at a good angle —121°; and, as usual, each lies at right angles to the bearing of the star to which it pertains.

Attention is here directed to the fact that in that geographical position, when the altitude of Sirius was 15° 56½′ the corresponding altitude of Benetnasch could only be 16° 24½′—*neither more nor less,* because no other altitude of that star would give that time at ship. This amounts to saying that if, at a specified time, the altitude of any visible star be given to a computer *whose own position is known,* he can calculate what the altitude of any other visible star would be at the same instant and at the same place; or, in other words, the two sets of data are interchangeable. Again: take notice of the difference in the longitude of the centres or poles of the two circles. It amounts to 105° 44′ 22″ in arc, or 7h. 2m. 57·5s. in time, which is exactly equal to the difference of the Right Ascensions of the stars. A second reading of the chapter on "Time" will brighten up the memory as to how this can be. **Altitudes can be calculated.**

Having endeavoured briefly to explain some of the groundwork of the problem, we will now get on to the more practical part.

Unlike "Double altitudes" of the sun, in which the observer has to air his patience waiting till the difference of bearing is such as will give a sufficiently good "cut," *Astronomical Cross-bearings* (as the writer chooses to call them) can be obtained from *simultaneous* observations of the stars or planets without any interval whatever. This method possesses several striking advantages.

Advantages of simultaneous Star Altitudes

I. Stars may always be selected in such positions as will give the very best results, while the sun, on the contrary, is restricted in his application, the conditions not generally being matters of choice. Hence this method may be practised with equal success in all latitudes, and with high as well as moderate altitudes, although the latter are preferable, for reasons with which the reader is no doubt by this time familiar.

II. Since there is no interval between the observations, the method is free from possible errors in the ship's run, which errors, even when comparatively small, may seriously affect the result.

III. Several pairs of stars may be taken at the same time—one as a check upon the other, or three specially selected stars. (See next chapter.)

IV. One observation of either sun or star gives a "Line of bearing," which, valuable as it may be—so far as it goes—does not give a complete result. But it will be rare indeed that there will be any occasion to plot a "Line of bearing" by a single star; since, if one is visible, there are generally others also, some of which can be taken simultaneously, and so make it possible to define the ship's position exactly.

Calculation versus construction.

With the stars, also, calculation throughout is preferable to the chart, though in their case there is not altogether the same need for it as with the sun; since, if the stars be well chosen—and there is no reason why they should not be—the "Sumner lines" will not be open to the objection of making a bad "cut." However, this may be considered a matter of taste; but, for those who prefer calculation, Johnson's method is again available.

A few examples of the working will now be given. Instead of computing an imaginary series of observations, these are selected at random from among a number of others, taken on the same evening. The results in every case agreed within a 1′ or so. Were it not that the writer *knows* the great accuracy attainable with stars, and how superior they are to the sun, he would scarcely take up time and space to advocate their adoption.

It is necessary to notice two points of importance about the work of the * Benetnasch.

(1.) As its declination exceeds 23°, the azimuth cannot be taken out by inspection from Burdwood or Davis. This will sometimes occur in practice, but it is no longer a stumbling-block, since, as shewn on pages 423-426, a very few figures from tables A and B will give the "error" of any star likely to be selected. Herein lies the value of these tables in connection with Johnson's method. Should the stars lie within the scope of Burdwood or Davis, their azimuths are at once taken out by inspection, and the "error" follows from Table C. But should the declinations exceed 23°, the "error" can be had *direct* from A and B without any knowledge of the azimuth. There is no doubt, now that the A B C tables have been extended, many navigators will use them to the entire exclusion of Burdwood and Davis. In fact, with *Lecky's* A B C tables and *Johnson's* method, the navigator is armed at all points, and ready for any emergency.

The A B C Tables again to the front.

(2.) Benetnasch being a circumpolar * does not set to an observer North of 40°, and, consequently, it may have any hour-angle up to 12 hours east or west of the meridian.

Log sine square.

In the preceding example, its hour-angle or meridian distance is 9h. 23m. 38s., which is not contained in some of the epitomes, although occasionally a suitable table is given, which extends up

At 6h. 11m. on Saturday evening, February 21st, 1880, the following simultaneous observations of Sirius and Benetnasch were made on the bridge of the (s.s.) "*British Crown*." Eye 30 feet. No index error. Cold fresh breeze at N.W.; moderately rough sea; clear, with passing clouds and light showers. Ship making S. 79° W. (true), 11 knots.

Position by D.R. { Latitude 51° 00¾′ N. / Longitude 17° 42′ W.

	H. M. S.
Time by chronometer	7 23 25
Chronometer slow	+ 4 21
G.M.T.	7 27 46
Sidereal time at G.M.N.	22 03 10·9
Acceleration for 7h. 28m.	+ 1 13·5
Sidereal time at Greenwich	29 32 10·4

	° ′
Observed altitude ✱ Sirius	16 5 E.
Table 38 of Raper	− 8¼
✱'s true altitude	15 56¾

	° ′
Observed altitude ✱ Benetnasch	16 33 E.
Correction	− 8¼
✱'s true altitude	16 24¾

Sirius.

	° ′	
✱'s Declination	16 33½ S.	
	90	
Polar distance	106 33½	0·01839
Assumed latitude	51 10¼	0·20273
✱'s true Altitude	15 56¾	8·74226
		9·97539
	173 40	
		8·93877
Half sum	86 50	
Remainder	70 53¼	

Bearing of ✱ S. E.

The contrary N. W.

Therefore, apply the correction for latitude to the South.

	H. M. S.	
Hour Angle	2 17 7·1	E. = S. 34° E
✱'s Right Ascension	6 39 53·7	
Sidereal Time at Ship	4 22 46·6	
Sidereal Time at Greenwich	5 32 10·4	
Longitude in time	1 9 23·8 =	
Longitude	17 21	W. by Sirius.
Correction	+ 21¾	W.
True longitude	17 42¾	West.

Benetnasch.

	° ′	
✱'s Declination	49 54¾	
	90	
Polar distance	40 5¼	0·19107
Assumed latitude	51 10¼	0·20273
✱'s true Altitude	16 24¾	9·77091
		9·78374
	107 40½	
		9·94845
	53 50¼	
	37 25½	

Bearing of ✱ N. E.

The contrary S. W.

Therefore, apply the correction for latitude to the South.

	H. M. S.	
Hour Angle	9 23 38·0	E. = N. 25° E.
✱'s Right Ascension	13 42 51·2	
Sidereal time at ship	4 19 13·2	
Sidereal time at Greenwich	5 32 10·4	
Longitude in time	1 12 57·2 =	
Longitude	18 14¼	W. by Benetnasch.
	17 21	W. by Sirius.

5·75) 53·25 (9·26 correction for latitude.
51·75
1500
1150
350

TABLE C

Bearing of Sirius	S. 34° E. — 2′·35 × 9′·26 = 21¾′	Correction for Long.
Bearing of Benetnasch	N. 25° E. — 3′·40 × 9′·26 = 31½′	Correction for Long.
Sum, being in different quarters	5′·75	

	° ′
Assumed latitude	51 10¼ N.
Correction	− 9¼
True latitude	51 1 North.

	° ′
Longitude by Benetnasch	18 14¼ W.
Correction	− 31½ E.
True longitude	17 42¾ West.

NOTE:—Unless required for some other purpose, the bearings need not be determined, as the "errors" can be taken out direct from Tables A and B.

to 12 hours. Should the navigator not possess the latter table, he need not consider the battle lost, as there is an easy dodge by which the desired end may be attained.

How to find Hour Angle when the regular Table is not available.

Take out the log. sine of *half* the log. of the hour angle; *double* it and turn it into *time*, and you have what you want. The log. of the hour-angle is 19·94845; halve it = 9·974225; this is the log. sine of 70° 27′ 17″, which, doubled, is 140° 54′ 34″ = 9h. 23m. 38s.

How to select Stars for Simultaneous Altitudes.

To select fitting stars for *Simultaneous Altitudes* is a simple matter. Choose any star or planet whose bearing from the meridian exceeds 14° or 15°. Face it squarely, and, extending the right or left arm upwards from the side, notice if it points to any other known star of the first, second, or third magnitude. Such a star will bear at right angles to the first one, and be in the best possible position for pairing with it. If you fail to find a star or planet so situated, take the next best you can get, but endeavour to avoid the difference in the bearings being *less* than 60°, or *more* than 120°. Also remember the "Danger-signal."

In working *Simultaneous Altitudes* by Johnson's method, it is by no means essential that they should be taken exactly at the same instant. The idea that two observers were required for this problem has often proved a bar sinister to its use. This we must remove forthwith, and shew that, by having all preparations made beforehand, one sextant, with a good man behind it, is quite equal to the occasion.

Electric lamp for sextant.

Place an officer at the chronometer, and take the sights yourself from behind the shelter of the bridge-cloth—*in clear weather, the higher the better.* Let a quartermaster attend with a bull's-eye or binnacle lamp by which to read off, or better still, have your sextant fitted with an electric lamp, as recommended on page 78. In this manner the two stars can easily be taken by an expert observer in from one to two minutes of each other, which is close enough together, even on board a "22-knotter," if the sights are good. If, however, clouds, or a ship crossing your bow, or the peak haulyards carrying away, should cause the 2nd observation to be deferred for a few minutes, the longitude by first star can be corrected for the run in the interval just as if it were a "Double Altitude." Of course, also, you won't forget to allow the difference of latitude made good, and apply it to the latitude used for 2nd observation.

The two following examples of *nearly* simultaneous altitudes, taken in this fashion, may be worked for practice. To convince yourself of the value of the method, work with a latitude purposely 10′ or 20′ in error—say 51° 10¼′ N., as in the preceding example:—

FEBRUARY 21ST, 1880, OBSERVED AS FOLLOWS.

	H. M. S.		° ′	
Time by chron.	7 25 5	* α Cygni (Deneb)	20 34½ W.	To be worked as a pair.
" "	7 27 7	* Dubhe	40 34 E.	
" "	7 34 28	* Alpheratz	35 37½ W.	To be worked as a pair.
" "	7 36 10	* Dubhe	41 25 E.	

Examples for practice.

All conditions the same as in the worked example.

These observations are *bona fide*, and although they come out well together, the evening was not by any means a favourable one; and the writer might easily have selected stars out of his work books agreeing closer, but these are preferred as a *fair average sample.*

It may not come amiss to some people to point out that if the star of lesser azimuth be only 10° or 12° from the meridian, the error in the assumed latitude should not exceed 7′ or 8′ to secure a first-class result; and, consequently, such small azimuths are objectionable. Alas! there is no rose without a thorn, and no man is infallible. This subject has already been fully discussed, but a reminder here may serve to emphasize it.

Limits of observation.

Where D.R. has been carried on for some days, and from the result of the calculation there is reason to suspect a grave error in the latitude worked with—say 40′ or upwards—it would be imperative, *in the objectionable cases alluded to,* to re-compute both sights with the amended latitude; and, since a good many of the figures first employed will still hold good, this can be done without any extra trouble to speak of. Anyhow it is better to incur the extra trouble than to lose your ship and possibly all hands. "One needs must when the Devil drives."

An old saying which still holds good.

With the lesser azimuth lying between 20° and 25°, no error in the latitude—likely to occur in decent practice—can sensibly affect the determination, so that one working should be sufficient.

As a specimen of *accurate* observation, take the following, made on the present voyage. About 7h. 22m. P.M., August 1st, 1880, the stars Altair (E.), and Arcturus (W.), gave *precisely* the same longitude; the third, Benetnasch (W.), differing only 1′. The Pole * was observed for latitude, and differed only *half a mile* from Antares to the Southward, the latter being worked as an Ex-meridian, with an hour-angle of 11m. 9s.

The observations were taken and calculated in the presence of the Chief Officer and Surgeon, and afterwards examined by them, "Cooking." so that "cooking" was impossible. They are not mentioned here in self-glorification, but merely to show what can be done with the stars, and what extremely satisfactory results are to be obtained when one understands and has practice at the work.

Of course simultaneous altitudes of two Planets, or of a star and a Planet, can be utilised in a precisely similar manner. An example of a star and a Planet coupled together, and worked by Johnson's method (modified), is given on the next page.

This modified example is rather different from the preceding, for instead of finding the Azimuths as hitherto, and with their aid unearthing the "Error" from Table C, the "Error" is now taken *direct* from Tables A and B, *without the intervention of the azimuth;* thus giving the navigator a choice of methods. Those, therefore, who have a predilection one way or the other can gratify it.

Here is the way the "Errors" are obtained from Tables A and B, pages 438-439 :—

* Procyon.

Lat. 40¼° N.	Hour-angle 2h. 46m.	A +	·955
Decl. 5¼ N.	" " "	B −	·145
		"Error"	·810

* Saturn.

Lat. 40¼° N.	Hour-angle 2h. 23m.	A +	1·174
Decl. 12 N.	" " "	B −	·364
		"Error"	·810

Though the "Error" is taken out here to three places of decimals, two are ample. It happens by a pure coincidence that both "Errors" have the same value.

Ringing the changes. This ignoring of the Azimuths, and taking the "Error" direct from Tables A and B, is of course also applicable to "Double Altitudes." To have two strings to your bow is a great convenience.

Should the Azimuths be wanted later on for some other purpose, you can take them from Table C by inspection. On page 449, with Lat. 40¼° and "Error" ·810, the Azimuth is 58¼°. These Tables enable the navigator to take advantage of every shift of wind; metaphorically speaking, he can never get jammed on a lee shore.

At 5h. 56m. on Monday evening, February 27th, 1882, the following nearly simultaneous observations of Procyon (E.) and planet Saturn (W.) were made on the bridge of the (s.s.) "*British King.*" Eye 30 feet. No index error. Moderate breeze at S.W.; smooth sea; fine and clear. Ship making N. 76° E. (true), 12½ knots.

Position by D.R. { Latitude 40° 10¾′ N. / Longitude 55° 41′ W.

	H. M. S.
Time by Chronometer	10 9 38
Chronometer fast	− 10 53
G.M.T.	9 58 45
Sidereal Time at G.M.N.	22 28 52
Acceleration for 10 hours	+ 1 39
Sidereal Time at Greenwich	8 29 16

Observed Alt. ✱ Procyon	39° 11′
Table 38 of Raper	− 6¾
✱'s true altitude	39 4¼

✱'s Declination	5° 31½′ N.	
	90	
Polar Distance	84 28½	0·00201
Latitude by D.R.	40 10¾	0·11688
✱'s true altitude	39 4¼	9·15069
		9·83209
	163 44	9·10167
Half Sum	81 52	
Remainder	42 47¾	

Bearing of Procyon S. E.

The contrary N. W.

Therefore, apply the correction for latitude to the North.

	H. M. S.
Procyon's Hour Angle	2 46 35
" Right Ascension	7 33 10
Sidereal Time at Ship	4 46 35
Sidereal Time at Greenwich	8 29 16
Longitude in Time	3 42 41 = 55° 40¼′ W.
Correction	− 3 applied to the East.
True Longitude	55° 37¼′ W.

	H. M. S.
Time by Chronometer	10 10 36
Chronometer fast	− 10 53
G.M.T.	9 59 43
Sidereal Time at G.M.N.	22 28 52
Acceleration for 10 hours	+ 1 39
Sidereal time at Greenwich	8 30 14

Observed alt. ✱ Saturn	47° 59′
Table 38 of Raper	− 6½
✱'s true altitude	47 52½

✱'s Declination	12° 4′ N.	
	90	
Polar distance	77 56	0·00970
Latitude by D.R.	40 10¾	0·11688
✱'s true altitude	47 52½	9·08615
		9·75985
	165 59¼	8·97258
Half Sum	82 59⅝	
Remainder	35 7	

Bearing of Saturn S. W.

The contrary N. E.

Therefore, apply the correction for latitude to the North.

	H. M. s.
Saturn's Hour Angle	2 22 44
" Right Ascension	2 25 13
Sidereal Time at Ship	4 47 57
Sidereal Time at Greenwich	8 30 14
Longitude in time	3 42 17 = 55° 34¼′ W. by Saturn.
	55° 40¼′ W. by Procyon.

1·6)60(3′·75 corr. for latitude.
48
—
120
112
—
80
80

Latitude worked with	40 10¾ N.
Correction	+ 3½
True Latitude	40 14¼ N.
Longitude by Saturn	55 34¼ W.
Correction	+ 3 applied to the W.
True Longitude	55° 37¼′ W.

Tables A and B give "error" { Procyon = 0′·8 × 3′·75 = 3′ correction for longitude. / Saturn = 0′·8 × 3′·75 = 3′ correction for longitude.

Sum 1′·6 being in different quarters.

At 10h. 5m. 13s. by the same chronometer, the observed altitude of the North ✱ was 41° 9½′; and at 10h. 15m. 13s. the observed altitude of the ✱ Rigel to the southward was 41° 21½′, all conditions same as above. When reduced to time corresponding to that of Procyon and Saturn, the North ✱ gives the latitude 40° 15′ N., and Rigel worked as an ex-merid., with an hour angle of 16m. 27s., gives the latitude as 40° 15½′ N. By a pure coincidence, Saturn happened to have precisely the same bearing West that Procyon had East. The error in the longitude, due to an error in the latitude worked with, was therefore the same for each of them.

CHAPTER XIV.

SYSTEMATIC ERRORS IN ALTITUDE, AND HOW TO TREAT THEM.

In the following brief analysis it is proposed to shew how—under certain conditions—the position of a ship may be accurately defined by simultaneous observations of three specially selected stars.

Errors of observation.

Let us suppose the existence of an unsuspected Arc-Error; and/or any personal peculiarity of vision or temperament whereby an individual has a habit of making the altitude too great or too little; and/or let the visible horizon be abnormally raised or depressed by refraction, so that the tabular values will be in error. Imagine any one of these conditions, or a combination of all three.

In such a case—by no means uncommon—it is clear that unless observations are capable of b[illegible] treated in some special manner, the positions deduced fro[illegible] ll be more or less erroneous and misleading, according [illegible]

It will now be dem[illegible] stars *favourably situated in azimuth* wou[illegible] handled, enable the Navigator to fix his [illegible] the most satisfactory manner, notwiths[illegible]rs of observation: the word "systemat[illegible] this problem the displacement [illegible]rm

Some conditions of the problem.

all round; the Index-Er[illegible]ne for all three altitudes; an[illegible]n or temperament to have m[illegible]o small. The argument is f[illegible], but failing any one of the[illegible] of cards. Herein lies its d[illegible]

There are three explana[illegible] *North* and *South* line repr[illegible] the continuous *East* and *We*[illegible] on th[illegible]llel of 50° North[illegible]

CHAPTER XIV.

SYSTEMATIC ERRORS IN ALTITUDE, AND HOW TO TREAT THEM.

In the following brief analysis it is proposed to shew how—under certain conditions—the position of a ship may be accurately defined by simultaneous observations of three specially selected stars.

Errors of observation.

Let us suppose the existence of an unsuspected Arc-Error; and/or any personal peculiarity of vision or temperament whereby an individual has a habit of making the altitude too great or too little; and/or let the visible horizon be abnormally raised or depressed by refraction, so that the tabular values will be in error. Imagine any one of these conditions, or a combination of all three.

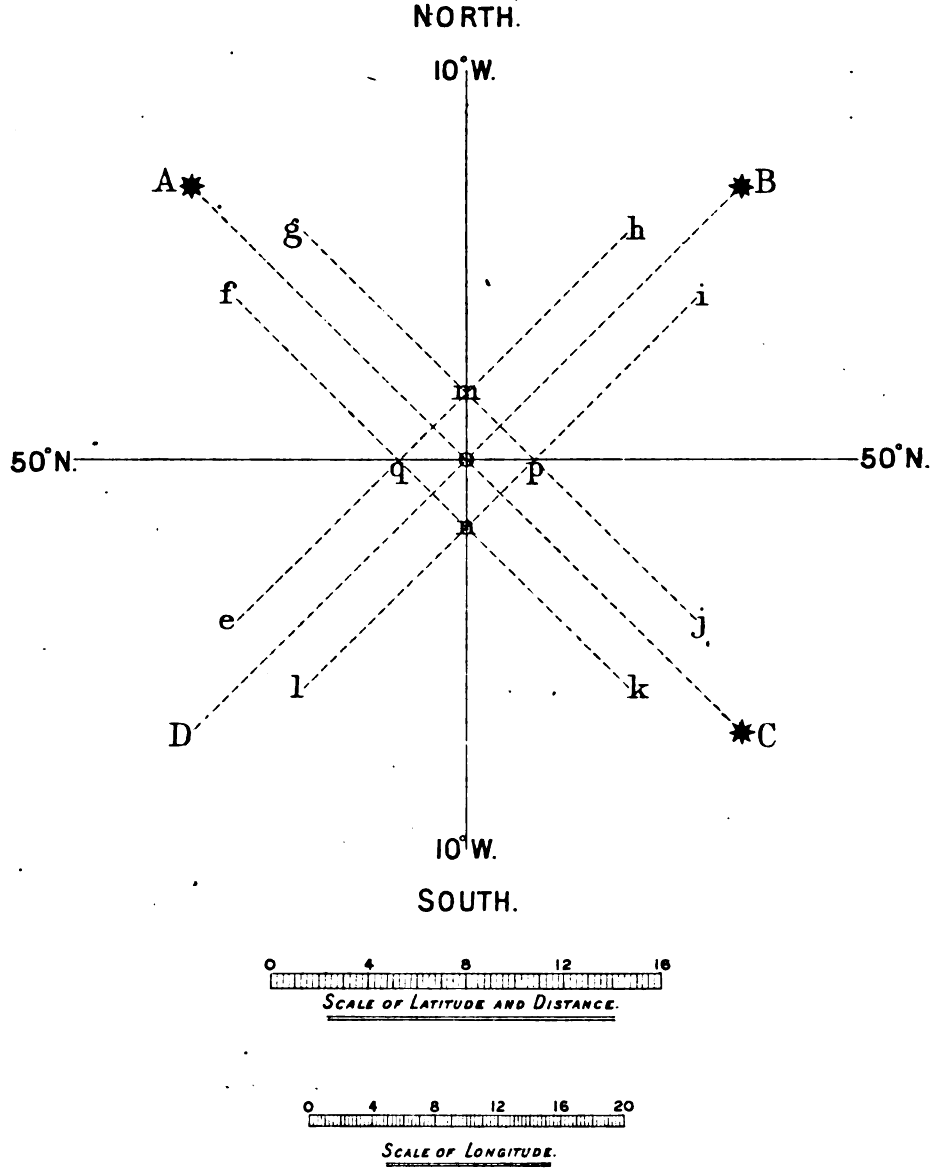
In such a case—by no means uncommon—it is clear that unless observations are capable of being treated in some special manner, the positions deduced from them will be more or less erroneous and misleading, according to circumstances.

It will now be demonstrated that *three* stars *favourably situated in azimuth* would, if "judgmatically" handled, enable the Navigator to fix his position in apparently the most satisfactory manner, notwithstanding systematic errors of observation: the word "systematic" is expressly used because in this problem the displacement of the horizon is assumed to be uniform *all round;* the Index-Error + or − is assumed to be the same for all three altitudes; and the observer's peculiarity of vision or temperament to have made all three equally too great or too small. The argument is founded principally on these premises, but failing any one of them it falls to the ground like a house of cards. Herein lies its danger.

Some conditions of the problem.

There are three explanatory Plates. In each the continuous *North* and *South* line represents the *Meridian*, say, of 10° W.; the continuous *East* and *West* line represents the *Prime Vertical* on the parallel of 50° North Latitude. The space between one

Plate X.



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dotted line and the next—measured square across—is equal to 2′ of distance. By attentively following the argument it will be seen that the true place of the observer *must* be where the continuous lines intersect at **o**.

Now to start fair and make the thing clear, let us assume first of all that there are absolutely *no* errors of observation: then for the ✱ **B** in the N.E. quadrant of Plate X., the "line of position" will be **AoC**, and the observer will be *somewhere* on it: for the ✱ **C** in the S.E. quadrant, the 'line of position' will be **BoD**, and the observer will be somewhere on *it* also. If, therefore, he is both on **AoC** and **BoD**, he must be at **o**, their point of intersection, which at once settles both his Latitude and Longitude. So far so good, and we are gradually working up to the peculiarities of this peculiar problem.

Sticking to Plate X., let us next imagine the altitude to have been incorrect, though the observer is not aware of this, and that the ultimate effect of the three possible errors previously referred to is to make both altitudes *too great* by 2′ of arc; then for ✱ **B** the 'line of position' seemingly becomes **gj**, and for ✱ **C** it becomes **li**; these intersect at **p**, and although this places the Longitude 4′ 24″ too far East (see Table D, Lat. 50°, Az. 45°), *the Latitude remains as before.* **Altitudes too great.**

In the same way, if we work with altitudes which are *too small* by 2′ of arc, we get for ✱ **B** the 'line of position' **fk**, and for ✱ **C** the "line of position" **he**; these intersect at **q**, making the Longitude this time 4′ 24″ too far West; *but the Latitude remains 50° N. as before.* **Altitudes too small.**

Thus, *by* following the rule to observe stars *on the same side of the meridian, but at an equal angle on each side of the Prime Vertical,* we obtain the true LATITUDE, irrespective of systematic errors of observation.

In the same manner we can deal with the LONGITUDE:—Observe two stars, *both North or both South of the Prime Vertical, but on different sides of the Meridian,* and as nearly as possible at the same angle East and West of it. In Plate X., ✱ **B** bearing N.E. and ✱ **A** bearing N.W. fulfil these conditions to a nicety.* Now, if the altitudes were free from spot or blemish, the 'position line' for ✱ **A** would be **BoD**, and for ✱ **B** would be **AoC**,

* Of course, if so desired, a fourth star might be selected in the N.E. quarter to combine with ✱ A, but in this particular case, where the azimuths are exactly equal in respect both of Meridian and Prime Vertical, it would involve extra labour without any corresponding advantage; we will therefore remain constant to our first love.

and their intersection at **o** would be the true place of the observer; but if the altitudes should happen to be 2′ *too great*, the 'line of position' for * **A** seemingly becomes **h e**, and for * **B** it becomes **g j**; they intersect at **m**, and although the Latitude is now nearly 3′ too far North, *the Longitude remains as before.*

Again, if we work with altitudes which are *too small* by 2′ of arc, we recede from the stars, and for **A** the 'line of position' becomes **l i**, and for **B** it becomes **k f**; these intersect at **n**, and although the latitude is now nearly 3′ too far South, *the Longitude remains as before.*

Best azimuths for simultaneous alts.

It follows that, as the stars **A** and **B** give the *Longitude* as 10° W., and the stars **B** and **C** give the *Latitude* as 50° N., the observer's position at **o** is accurately determined. Of course, it will be understood that the *true* 'Lines of position' are in just the opposite direction to those here mentioned:—for example, in the case of a star bearing, say, East, if an altitude were used which was subsequently discovered to be 2′ in excess of the true altitude, the 'Line of position' would have to be shifted that much to the westward of the place first assigned to it.

Objectionable cases.

To further illustrate the subject, two more Plates are given shewing the magnified effect of errors of altitude when the azimuths are unfavourable through the angles being too acute.

In Plate XI., * **B** and * **C** are each 11° on opposite sides of the Prime Vertical (= Az. 79°), and, assuming the altitudes to be 2′ *too great*, the position would seemingly be at **p** on the parallel of 50° N., and the Longitude would be 3′ 10″ too far East. With altitudes *too small* by the same amount, the position would seemingly be at **q**, *still on the parallel of 50°*, but 3′ 10″ too far West (see Table D).

Referring to Plate XII., the stars **B** and **C** are both on the same side of the Prime Vertical, but 11° on opposite sides of the Meridian, and, assuming the altitudes to be 2′ *too great*, the resulting position would be at **m** on the meridian of 10° W., and the Latitude would be too far North by a fraction over 2′. With altitudes *too small* by the same amount, the resulting position would be at **n**, still on the meridian of 10° W., but the Latitude would be slightly over 2′ too far South.

Good in Theory, but unsound in practice.

Thus, *according to this problem*, no matter how small the difference between the bearings, so long as they are at equal distances from the Meridian and Prime Vertical respectively, a correct result is obtained. But would it be so in practice? The writer thinks not.

Plate XI.

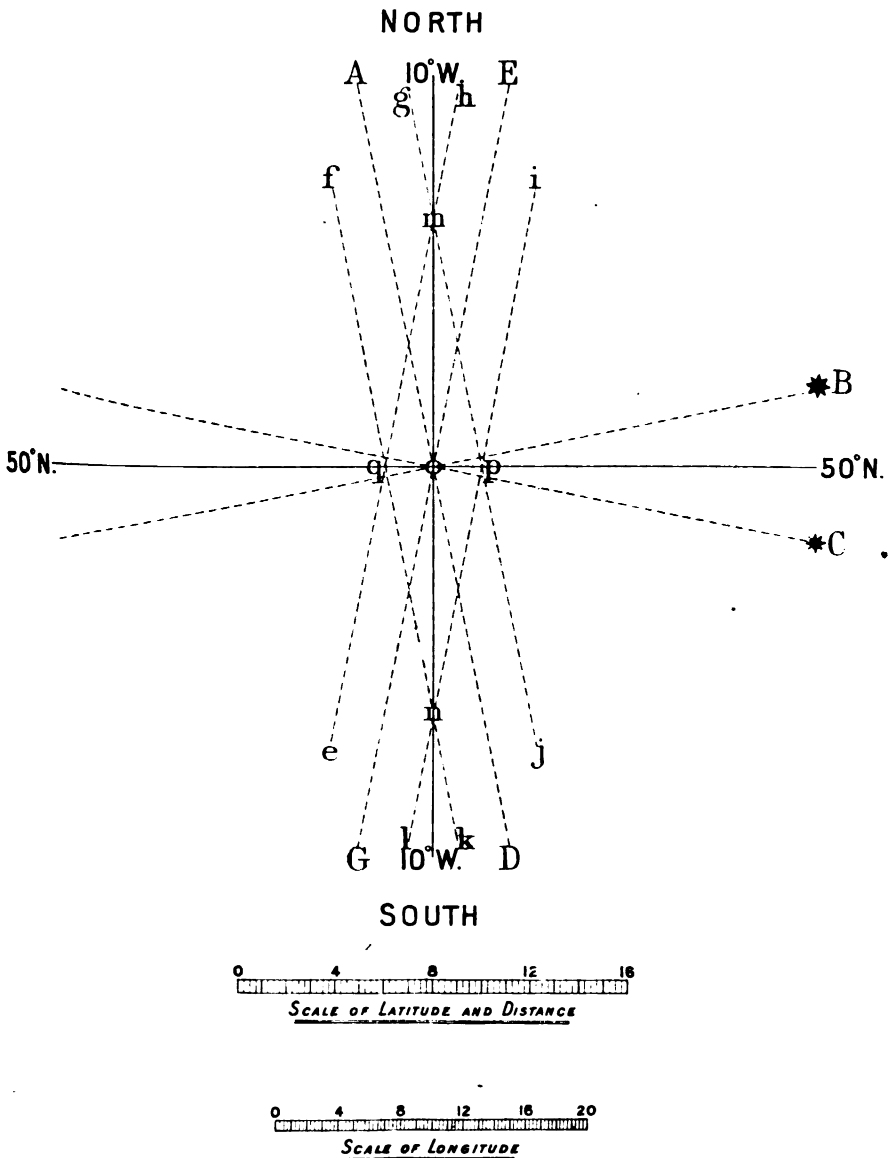

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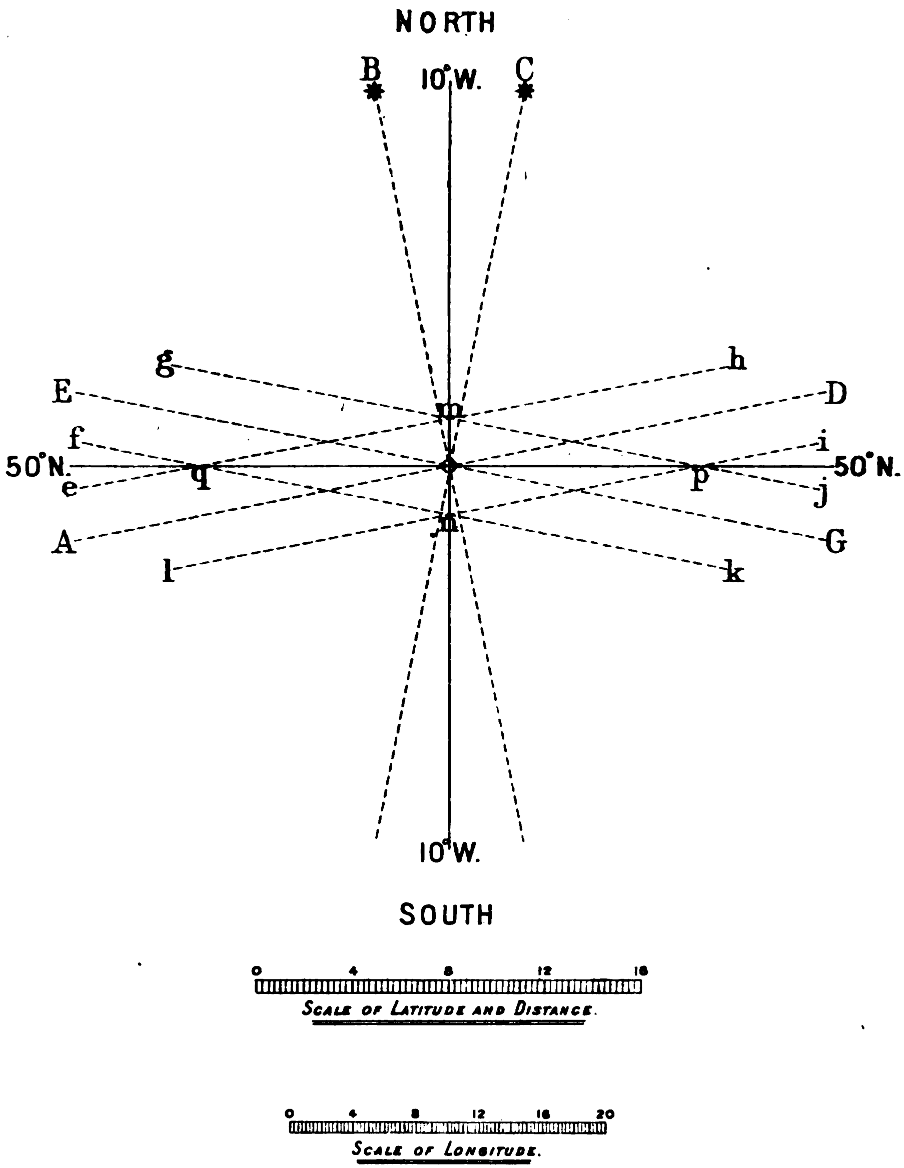
Plate XII.



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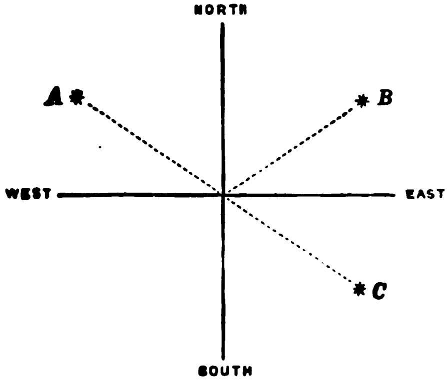
This problem smacks strongly of *Theory*, for it is hardly likely that stars will always be found so very accommodating in their azimuths as here depicted. But to shew the *Principle* it was necessary to draw the stars at points equidistant from the Meridian and Prime Vertical respectively. There is no doubt that a most perfect position would result from stars situated as in Plate X, if worked in the ordinary manner. Either pair alone would do well, but when checked by the third star the 'Fix' would be simply inimitable.

Stars can be found with azimuth approximating

The subjoined cut shews another favourable case.



Here, between the two northern stars the difference of bearing is 10 points, and between the two eastern stars it is 6 points. Or, by slueing the diagram a quarter of the way round, you get another suitable combination.

And now for a very necessary word of caution. *On no account must this Three-star problem be confounded with the legitimate 'Double' or 'Simultaneous Altitudes' problem described and recommended in previous chapters.* Though, in each case, the *figuring* would be the same, the *conclusions* would be exactly the reverse. It is necessary to make this clear.

A distinction *with a* difference.

In the ordinary working of the problem as presented in chapters XII. and XIII., should errors of altitude exist (and to some extent this is *always* the case), they are not necessarily taken to be uniform, either in amount or direction; that is to say, the error in altitude of one star may be + 1′ 45″, whilst that of the other may be − 0′ 20″. This is a safe kind of assumption, for no observer afloat can guarantee absolute uniformity. Shortly after sunset the writer generally found his western stars rather the more accurate, because on that side the horizon was at its best; whereas, before sunrise, the eastern altitudes gave best results for the same reason.

Again, there need not be the same symmetrical disposition in azimuth in relation to the Meridian and Prime Vertical: the observer is not bound hand and foot in these matters like he is in the three-star problem. In this latter, conditions of observation are required which are practically unattainable. It would be unsafe to assume them; and, speaking for himself, the writer would not like to trust to any such vain imaginings. They may be very nice on paper, but they won't hold water in practice.

Author's own opinion.

The question will probably present itself to the reader, 'Why then has this three-star problem been introduced to my notice'? There are two reasons—1. Because it is of value as elucidating a principle, but whether this principle can be safely accepted by the average navigator is quite another thing. 2. Because in some quarters an endeavour has been made to give prominence to the method, and unless its fallacies are exposed, the inexperienced might come to grief over it.

All along in 'Wrinkles,' the burden of the song has been that according as observations *approached the Meridian,* so their value increased for the determination of LATITUDE; and *per contra,* that as they receded from the Meridian and *approached the Prime Vertical,* their value increased for LONGITUDE. But this three-star problem would seem to say quite the contrary: no doubt, *if the stipulated conditions could only be ensured,* it would achieve what it sets out to do, and in the hands of an expert might be of some service; but for use by the multitude its tendency is dangerous.

Author's own advice.

Without this explanation, very false conclusions might be drawn from what is known as the 'three-star problem,' and the navigator is counselled to put it behind him, and go in for the pure and unadulterated article, about which we will now add a few more words before winding up this the last chapter on the astronomical methods of finding a ship's position at sea.

By again looking at Plates X. XI. and XII., and this time considering them wholly from the point of view of the ordinary 'Simultaneous Altitudes' problem, it will be seen that by assuming the possibility—nay probability—of an inequality in the errors of altitude, the + and − 'position lines' of two stars (ignore the third one altogether) will form a parallelogram, the size and shape of which will depend upon two things:—(1) upon the *magnitude* of the assumed errors of altitude; (2) upon the *difference* in azimuth of the selected stars. The nearer this difference is to 90°, the smaller will be the parallelogram and the nearer will it approach a perfect square in shape.

There are certain points in connection with this parallelogram which it will be well to consider.

The *Mean* Azimuth. It will be found that one of its diagonals will invariably lie in the direction of the *Mean Azimuth:* sometimes it will be the longer of the two which will do so; at others it will be the shorter. The latter case, however, is the one which will generally have to be dealt with, because nine times out of ten the difference of bearing—more particularly with sun observations—will be *less* than 8 points; when *more*, it would be the longer diagonal which would lie in the direction of the *Mean Azimuth.* This fact can be turned to account in the selection of stars according to the requirements of the moment, for it is obvious that, in the case of an elongated parallelogram such as shewn in Plates XI. and XII., the position is defined within narrower limits in the direction of the short diagonal than it is in the direction of the long one. Taking Plate XI., it will be seen that the ship's position is much less uncertain in Longitude than it is in Latitude. The *extreme* error of Longitude is only 6·34′ = 4·07 miles distance; whereas, in Latitude, it amounts to 21′—a very great difference.

To turn the parallelogram to best advantage.

Under the conditions of Plate XII. the position is much better defined in Latitude than it is in Longitude. For example, the *extreme* limit of error in Latitude is only 4·07′, whereas, in Longitude, it amounts to 32·6′ = 21 miles of distance.

Difference of Azimuth. Another feature of the parallelogram is that so long as the angular *difference* between the two azimuths does not vary, the size and shape of the parallelogram will be the same, no matter in what direction the *mean azimuth* may lie. In other words, any alteration in the direction of the *Mean Azimuth* has no other effect than to turn it on its centre as on a pivot. This also is an important fact.

Now, if the allowance made by the navigator is sufficient to cover the error in altitude, the place of the ship will be within the parallelogram, which may therefore be described as an 'area of position.' But this is not the case with the three-star problem. There is no such area: the 'position lines' are supposed to intersect definitely on the ship's Meridian and Prime

Vertical respectively. A man must be sanguine indeed, who, with his eyes open to the various sources of error, can bring himself to believe that such mathematical precision is attainable at sea by the proposed treatment.

Reverting to the 'area of position,' it need scarcely be said that its size, under favourable circumstances, may be very small; nevertheless it will exist, and therefore as altitudes at sea are uncertain—sometimes very uncertain—the prudent man, after fixing a *point* on the chart representing the position by calculation, will fence it round in accordance with his estimate of maximum error in alt. The result will be a *space* within which the ship will most probably be. Errors in the G.M.T. are not considered.

Fencing the position.

Should his stars north be balanced by stars south, and those east by those west, there will be no need of the fencing; the positions will speak for themselves (*vide* pages 376-377, and 476-477).

It may never have struck the reader, so it is as well to point out that, a star on the meridian combined with one on the P.V. is only a particular case of simul. alts., and by constructing the figures it will be seen that the diagonals run intermediate to the cardinal points, one being in the direction of the *Mean Azimuth.*

Construction very instructive

By way of instructing himself, the advanced student would do well to construct half a dozen diagrams with stars at unequal azimuths from the Meridian and Prime Vertical. Let him draw the fixed Meridian and Prime Vertical lines with a red pencil—the direction of the subsequent errors will be more apparent—and in plotting, use any scale he has a mind to—say an inch to a mile. The varying effects, due to changes in the azimuths themselves and in their differences, will be very evident. They will be made more so by lightly shading the 'Position area.'

Use of "set-squares."

To get the Azimuthal angles laid down, a protractor (see footnote page 116) is necessary, and a lot of trouble will be saved if the student knows how to substitute a couple of 'set-squares' for the parallel ruler. If he does not know, let him find out from the very first obliging draughtsman he may happen to meet. These little diagrams will enable him to judge of what he may expect under certain circumstances. Each Master, and indeed each Officer, should get "Chips" to make him a small yellow pine drawing board—say 15 in. by 12 in. by ¾ in.—with a T square to match. To keep the board from warping, it ought to be clamped with mahogany. This is a very useful piece of a navigator's equipment, and should fully repay him for whatever care is taken of it. By cleating it flat against a bulkhead it will not be in the way at wrong times. Then with these tools, half a quire of drawing paper, Imperial size 30 × 22, to be used in *half* sheets, and a few drawing pins, he will be set up.

To this chapter is appended Table D, shewing the error caused in the Longitude by an error of 1′ in the altitude. It is useful in many ways. It shews at sight the degree of dependence of any observation, and if at any time an erroneous altitude has been worked with, the Longitude can be readily corrected without the trouble of going over the whole operation afresh. Supposing the true altitude to be greater than the one worked with, it is evident that the Longitude will be thrown to the same side of the meridian as the sun, thus in the forenoon, a greater altitude would make the Longitude more easterly; and in the afternoon it would make it more westerly. In each case the hour-angle is made smaller; in other words, as you approach the sun (shewn by an increase in altitude), your distance from him both in time (hour-angle), and in arc (longitude), diminishes. You need not burst a blood-vessel to see this. The opposite effect would of course be produced if the true altitude were less than the one worked with. In this case the observer and his Longitude would have to retire from the sun.

Effect of altitude upon the hour-angle.

Again, if, as is usual, a number of sights be taken, the first need only be worked in full, as the Table will give the corrections for the remainder. The azimuth is required for this also, but the reader already knows how to find it in a very few seconds. There is just one point about this last use of Table D:—If the sights have been taken slowly so that the interval between the first and last of a set of five should be, say, 10 min., and the azimuth happens to be changing rapidly, the corrections would be slightly inaccurate. This could be overcome by working the *middle* sight of the set, thereby halving the error in each direction: the corrections due to the azimuth of this middle sight would then be very close indeed. As pointed out in previous pages, there are times when the change of azimuth is extremely slow, and at such times this dodge would save a lot of figures. Perhaps some one will say,—why not mean the five sights right off and then there will be no need of all this fuss about nothing? Agreed, but by so doing it is impossible to detect mistakes either in the reading of the sextant, in the chronometer times, or in the work-

Some uses of Table D.

ing; such things *do* happen, and to treat each sight separately is an undoubted check. Table D affords a means of doing it without any extra labour worth speaking about.

Ship's position, how defined. As the position of a ship at sea is much more often represented by a *space* than a mere *point*, and as this space takes the form of a parallelogram, it may be interesting to know how to calculate the area of such parallelogram. Rule :—

The logarithm of the area = the sum of the logarithms of the two sides, and of the sine of the contained angle diminished by 10.

EXAMPLE.

What is the number of square miles in a parallelogram with sides equal to 10·52 and contained angle = 11° ?

Side 10·52	..............................Log	1·022016
		2
		2·044032
Angle 11°	..............................Sine	9·280599
	Square miles 21·12 =	1·324631

Area of Plate XI., parallelogram. By way of practice, find the area of the parallelogram in Plates XI. or XII. If correctly worked, the answer will come out as 42·716 square miles; that is to say, if the elongated parallelogram were converted into a square of the same area, each side of the square would measure rather more than 6½ miles in length.

A proof of this is easy. In figure on page 705 produce DC, and drop a perpendicular from A to cut DC produced in E. The area of triangle DAC = ½ (AE × CD), and whole area of parallelogram ABDC = (AE × CD). But angle ACE = angle BDC, which is the angle contained by the two sides BD, DC; and therefore AE = AC sin ACE = AC sin BDC. Hence, area of parallelogram ABDC = AE × CD = AC × sin BDC × CD.

LECKY'S TABLE D.

(Entered at Stationers' Hall, September 1st, 1892.)

FORMULA USED IN ITS CONSTRUCTION.

D = Cosec. of Azim. × Secant of Latitude.

EXAMPLE.

Azimuth 20°	- - -	Cosec.	10·4659483
Latitude 45°	- - - -	Secant	10·1505150 +
D = 4′·1349	- - -		= 0·6164633

This Table is an extension of Table II. of previous editions of "Wrinkles," and has been calculated and checked with great care. Like Table C, the values can be taken out of the ordinary Traverse Table by a double entry.

For example :—

1. With the *Latitude* (45°) as a *Course*, look for, say, 100 in the *Latitude* column, and against it, in the *Distance* column, will be found a number (141·5).
2. With *Bearing* (20°) as a *Course*, and against 141·5 in a *Departure* column, will be found 413·6 in a *Distance* column. Divide this by 100 and you get 4′·136, or nearly the same as by logarithms.

The number 100 is employed instead of the unit 1, in order to get three places of decimals in the answer. 1,000 would be better still, if the Traverse Tables only ran up to it.

Or D may be found thus :—when working the ordinary chronometer problem (page 478) take out the Logarithmic Tabular Difference (for say 100″) of the cosine of the ½ sum, and to it add the Log. Tab. Diff. (for same number of ″) of the sine of the remainder. Multiply by 2, and divide the product by the Log. Tab. Diff. (for same number of ″) of the sine of half the Hour-angle.

The quotient will be D in seconds of Time

TABLE D.

Shewing the error produced in the Longitude by an error of 1′ in the Altitude.

Lat.	TRUE AZIMUTH.														
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°
0°	57·30	28·65	19·11	14·34	11·47	9·567	8·206	7·185	6·392	5·759	5·241	4·810	4·445	4·134	3·864
1	57·31	28·66	19·11	14·34	11·48	9·568	8·207	7·186	6·393	5·760	5·242	4·810	4·446	4·134	3·864
2	57·33	28·67	19·12	14·34	11·48	9·573	8·211	7·190	6·396	5·762	5·244	4·813	4·448	4·136	3·866
3	57·38	28·69	19·13	14·36	11·49	9·580	8·217	7·195	6·401	5·767	5·248	4·816	4·452	4·139	3·869
4	57·44	28·72	19·15	14·37	11·50	9·590	8·226	7·203	6·408	5·773	5·254	4·821	4·456	4·144	3·873
5	57·52	28·76	19·18	14·39	11·52	9·603	8·237	7·213	6·417	5·781	5·261	4·828	4·462	4·149	3·878
6°	57·61	28·81	19·21	14·41	11·54	9·619	8·251	7·225	6·428	5·790	5·270	4·836	4·470	4·156	3·885
7	57·73	28·87	19·25	14·44	11·56	9·639	8·267	7·239	6·440	5·802	5·280	4·846	4·479	4·165	3·893
8	57·86	28·94	19·30	14·48	11·59	9·661	8·286	7·256	6·455	5·815	5·292	4·857	4·489	4·174	3·902
9	58·01	29·01	19·35	14·51	11·62	9·686	8·308	7·275	6·472	5·831	5·306	4·870	4·501	4·185	3·912
10	58·18	29·10	19·40	14·56	11·65	9·714	8·332	7·296	6·491	5·848	5·322	4·884	4·514	4·197	3·923
11°	58·37	29·19	19·46	14·60	11·69	9·746	8·359	7·320	6·512	5·867	5·339	4·900	4·529	4·211	3·936
12	58·58	29·29	19·53	14·66	11·73	9·780	8·389	7·346	6·535	5·887	5·358	4·917	4·545	4·226	3·950
13	58·81	29·41	19·61	14·71	11·78	9·818	8·421	7·374	6·561	5·910	5·379	4·936	4·562	4·242	3·965
14	59·05	29·53	19·69	14·77	11·82	9·860	8·457	7·405	6·588	5·935	5·401	4·957	4·582	4·260	3·982
15	59·32	29·66	19·78	14·84	11·88	9·904	8·495	7·439	6·618	5·962	5·426	4·979	4·602	4·279	4·000
16°	59·61	29·81	19·88	14·91	11·94	9·952	8·536	7·475	6·650	5·991	5·452	5·004	4·625	4·300	4·019
17	59·92	29·96	19·98	14·99	12·00	10·00	8·580	7·514	6·685	6·022	5·480	5·030	4·649	4·322	4·040
18	60·25	30·13	20·09	15·07	12·06	10·06	8·628	7·555	6·721	6·055	5·511	5·057	4·674	4·346	4·063
19	60·60	30·30	20·21	15·16	12·13	10·12	8·678	7·599	6·761	6·091	5·543	5·087	4·702	4·372	4·086
20	60·98	30·49	20·33	15·26	12·21	10·18	8·732	7·646	6·803	6·128	5·577	5·118	4·731	4·399	4·112
21°	61·38	30·69	20·47	15·36	12·29	10·25	8·789	7·696	6·847	6·168	5·614	5·152	4·762	4·428	4·139
22	61·80	30·90	20·61	15·46	12·37	10·32	8·850	7·750	6·894	6·211	5·652	5·187	4·795	4·458	4·167
23	62·25	31·13	20·76	15·57	12·46	10·39	8·914	7·806	6·945	6·256	5·693	5·225	4·829	4·491	4·197
24	62·72	31·37	20·92	15·69	12·56	10·47	8·982	7·865	6·997	6·304	5·737	5·265	4·866	4·525	4·229
25	63·22	31·62	21·08	15·82	12·66	10·56	9·054	7·928	7·053	6·354	5·783	5·307	4·905	4·561	4·263
26°	63·75	31·88	21·26	15·95	12·77	10·64	9·129	7·994	7·112	6·407	5·831	5·351	4·946	4·599	4·299
27	64·31	32·16	21·44	16·09	12·88	10·74	9·209	8·064	7·174	6·463	5·882	5·398	4·989	4·639	4·336
28	64·89	32·45	21·64	16·24	12·99	10·84	9·293	8·138	7·240	6·522	5·936	5·447	5·035	4·682	4·376
29	65·51	32·76	21·85	16·39	13·12	10·94	9·382	8·215	7·309	6·584	5·992	5·499	5·083	4·726	4·418
30	66·16	33·09	22·06	16·55	13·25	11·05	9·475	8·297	7·381	6·650	6·052	5·554	5·133	4·773	4·461
31°	66·85	33·43	22·29	16·72	13·39	11·16	9·573	8·383	7·458	6·718	6·114	5·611	5·186	4·822	4·508
32	67·57	33·79	22·53	16·90	13·53	11·28	9·676	8·473	7·538	6·791	6·180	5·672	5·242	4·874	4·556
33	68·32	34·17	22·78	17·09	13·68	11·41	9·784	8·567	7·622	6·867	6·249	5·735	5·301	4·929	4·607
34	69·11	34·56	23·05	17·29	13·84	11·54	9·898	8·667	7·711	6·946	6·322	5·802	5·362	4·986	4·660
35	69·95	34·98	23·33	17·50	14·01	11·68	10·02	8·772	7·804	7·030	6·398	5·872	5·427	5·046	4·717
36°	70·83	35·42	23·62	17·72	14·18	11·83	10·14	8·882	7·902	7·118	6·478	5·945	5·495	5·109	4·776
37	71·75	35·88	23·92	17·95	14·37	11·98	10·27	8·997	8·004	7·211	6·562	6·022	5·566	5·176	4·838
38	72·71	36·36	24·25	18·19	14·56	12·14	10·41	9·118	8·112	7·308	6·651	6·104	5·641	5·246	4·903
39	73·73	36·87	24·59	18·45	14·76	12·31	10·56	9·246	8·226	7·410	6·744	6·189	5·720	5·319	4·972
40	74·80	37·40	24·94	18·71	14·98	12·49	10·71	9·380	8·345	7·518	6·841	6·279	5·803	5·396	5·044
41°	75·92	37·97	25·32	18·99	15·20	12·68	10·87	9·521	8·470	7·630	6·944	6·373	5·890	5·477	5·119
42	77·10	38·56	25·71	19·29	15·44	12·87	11·04	9·669	8·602	7·749	7·052	6·472	5·982	5·562	5·199
43	78·35	39·18	26·13	19·60	15·69	13·08	11·22	9·825	8·741	7·874	7·166	6·576	6·078	5·652	5·283
44	79·65	39·83	26·56	19·93	15·95	13·30	11·41	9·989	8·887	8·006	7·286	6·686	6·180	5·746	5·371
45	81·03	40·52	27·02	20·27	16·23	13·53	11·60	10·16	9·040	8·144	7·412	6·802	6·287	5·846	5·464
46°	82·48	41·25	27·51	20·64	16·52	13·77	11·81	10·34	9·202	8·290	7·544	6·924	6·399	5·951	5·562
47	84·02	42·01	28·02	21·02	16·82	14·03	12·03	10·54	9·373	8·444	7·685	7·052	6·518	6·061	5·665
48	85·63	42·82	28·56	21·42	17·15	14·30	12·26	10·74	9·553	8·606	7·832	7·188	6·644	6·178	5·774
49	87·34	43·68	29·12	21·85	17·49	14·58	12·51	10·95	9·744	8·778	7·988	7·331	6·776	6·301	5·889
50	89·14	44·58	29·73	22·30	17·85	14·88	12·77	11·18	9·945	8·959	8·153	7·483	6·916	6·431	6·011
51°	91·05	45·53	30·36	22·78	18·23	15·20	13·04	11·42	10·16	9·151	8·328	7·643	7·064	6·568	6·139
52	93·07	46·54	31·04	23·28	18·64	15·54	13·33	11·67	10·38	9·354	8·513	7·812	7·221	6·714	6·276
53	95·21	47·61	31·75	23·82	19·07	15·90	13·63	11·94	10·62	9·569	8·708	7·992	7·387	6·868	6·420
54	97·48	48·75	32·51	24·39	19·52	16·28	13·96	12·22	10·88	9·797	8·916	8·183	7·563	7·032	6·573
55	99·90	49·96	33·31	24·99	20·00	16·68	14·31	12·53	11·14	10·04	9·137	8·386	7·750	7·207	6·736
56°	102·5	51·24	34·17	25·64	20·52	17·11	14·67	12·85	11·43	10·30	9·372	8·601	7·950	7·392	6·909
57	105·2	52·61	35·08	26·32	21·07	17·57	15·07	13·19	11·74	10·57	9·623	8·831	8·162	7·590	7·094
58	108·1	54·07	36·06	27·05	21·65	18·05	15·48	13·56	12·06	10·87	9·890	9·076	8·389	7·800	7·291
59	111·3	55·63	37·10	27·83	22·28	18·57	15·93	13·95	12·41	11·18	10·18	9·339	8·631	8·026	7·502
60	114·6	57·31	38·21	28·67	22·95	19·13	16·41	14·37	12·78	11·52	10·48	9·619	8·891	8·267	7·727

To convert into Time, multiply by 4. Thus 114′·6 × 4 = 7m 38s·4.
This applies also to the quantities in Table C.

TABLE D.

Shewing the error produced in the Longitude by an error of 1′ in the Altitude.

Lat.	TRUE AZIMUTH. 16°	17°	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°
0	3·628	3·420	3·236	3·072	2·924	2·790	2·669	2·559	2·459	2·366	2·281	2·203	2·130	2·063	2·000
1	3·629	3·421	3·237	3·072	2·924	2·791	2·670	2·560	2·459	2·367	2·282	2·203	2·130	2·063	2·000
2	3·630	3·422	3·238	3·073	2·926	2·792	2·671	2·561	2·460	2·368	2·283	2·204	2·131	2·064	2·001
3	3·633	3·425	3·241	3·076	2·928	2·794	2·673	2·563	2·462	2·369	2·284	2·206	2·133	2·065	2·003
4	3·637	3·429	3·244	3·079	2·931	2·797	2·676	2·566	2·465	2·372	2·287	2·208	2·135	2·068	2·005
5	3·642	3·433	3·248	3·083	2·935	2·801	2·680	2·569	2·468	2·375	2·290	2·211	2·138	2·071	2·008
6	3·648	3·439	3·254	3·088	2·940	2·806	2·684	2·573	2·472	2·379	2·294	2·215	2·142	2·074	2·011
7	3·655	3·446	3·260	3·095	2·946	2·811	2·690	2·579	2·477	2·384	2·298	2·219	2·146	2·078	2·015
8	3·664	3·454	3·268	3·102	2·953	2·818	2·696	2·584	2·483	2·389	2·304	2·224	2·151	2·083	2·020
9	3·673	3·463	3·276	3·110	2·960	2·825	2·703	2·591	2·489	2·396	2·310	2·230	2·157	2·088	2·025
10	3·684	3·473	3·286	3·119	2·969	2·833	2·711	2·599	2·497	2·403	2·316	2·237	2·163	2·094	2·031
11	3·696	3·484	3·297	3·129	2·979	2·843	2·719	2·607	2·505	2·410	2·324	2·244	2·170	2·101	2·037
12	3·709	3·497	3·308	3·140	2·989	2·853	2·729	2·616	2·514	2·419	2·332	2·252	2·178	2·109	2·045
13	3·723	3·510	3·321	3·152	3·001	2·864	2·740	2·627	2·523	2·428	2·341	2·261	2·186	2·117	2·053
14	3·739	3·525	3·335	3·166	3·013	2·876	2·751	2·638	2·534	2·439	2·351	2·270	2·195	2·126	2·061
15	3·756	3·541	3·350	3·180	3·027	2·889	2·764	2·650	2·545	2·450	2·362	2·280	2·205	2·135	2·071
16	3·774	3·558	3·366	3·195	3·042	2·903	2·777	2·662	2·558	2·462	2·373	2·291	2·216	2·146	2·081
17	3·794	3·577	3·384	3·212	3·057	2·918	2·791	2·676	2·571	2·474	2·385	2·303	2·227	2·157	2·091
18	3·815	3·596	3·403	3·230	3·074	2·934	2·807	2·691	2·585	2·488	2·399	2·316	2·240	2·169	2·103
19	3·837	3·617	3·423	3·249	3·092	2·951	2·823	2·707	2·600	2·503	2·413	2·330	2·253	2·182	2·115
20	3·861	3·640	3·444	3·269	3·111	2·970	2·841	2·724	2·616	2·518	2·428	2·344	2·267	2·195	2·128
21	3·886	3·664	3·466	3·290	3·132	2·989	2·859	2·741	2·634	2·535	2·443	2·359	2·282	2·209	2·142
22	3·913	3·689	3·490	3·313	3·153	3·010	2·879	2·760	2·652	2·552	2·460	2·376	2·297	2·225	2·157
23	3·941	3·716	3·516	3·337	3·176	3·031	2·900	2·780	2·671	2·571	2·478	2·393	2·314	2·241	2·173
24	3·971	3·744	3·542	3·362	3·201	3·055	2·922	2·802	2·691	2·590	2·497	2·411	2·332	2·258	2·189
25	4·003	3·774	3·571	3·389	3·226	3·079	2·945	2·824	2·713	2·611	2·517	2·430	2·350	2·276	2·207
26	4·036	3·805	3·600	3·417	3·253	3·105	2·970	2·847	2·735	2·633	2·538	2·451	2·370	2·295	2·225
27	4·072	3·839	3·632	3·447	3·281	3·132	2·996	2·872	2·759	2·656	2·560	2·472	2·391	2·315	2·245
28	4·109	3·874	3·665	3·479	3·311	3·160	3·023	2·899	2·785	2·680	2·584	2·495	2·412	2·336	2·265
29	4·148	3·911	3·700	3·512	3·343	3·190	3·052	2·926	2·811	2·705	2·608	2·518	2·435	2·358	2·287
30	4·189	3·949	3·737	3·547	3·376	3·222	3·082	2·955	2·839	2·732	2·634	2·543	2·460	2·382	2·309
31	4·232	3·990	3·775	3·583	3·411	3·255	3·114	2·986	2·868	2·760	2·661	2·570	2·485	2·406	2·333
32	4·278	4·033	3·816	3·622	3·448	3·290	3·148	3·018	2·899	2·790	2·690	2·597	2·512	2·432	2·358
33	4·326	4·078	3·859	3·662	3·486	3·327	3·183	3·052	2·932	2·821	2·720	2·626	2·540	2·459	2·385
34	4·376	4·126	3·903	3·705	3·527	3·366	3·220	3·087	2·966	2·854	2·752	2·657	2·569	2·488	2·412
35	4·429	4·175	3·951	3·750	3·569	3·406	3·259	3·124	3·001	2·889	2·785	2·689	2·600	2·518	2·442
36	4·484	4·228	4·000	3·797	3·614	3·449	3·300	3·163	3·039	2·925	2·820	2·723	2·633	2·550	2·472
37	4·543	4·283	4·052	3·846	3·661	3·494	3·343	3·205	3·078	2·963	2·856	2·758	2·667	2·583	2·504
38	4·604	4·340	4·107	3·898	3·710	3·541	3·388	3·248	3·120	3·003	2·895	2·795	2·703	2·618	2·538
39	4·668	4·401	4·164	3·952	3·762	3·591	3·435	3·293	3·164	3·045	2·935	2·834	2·741	2·654	2·574
40	4·736	4·465	4·224	4·010	3·817	3·643	3·485	3·341	3·209	3·089	2·978	2·875	2·781	2·693	2·611
41	4·807	4·532	4·288	4·070	3·874	3·697	3·537	3·391	3·258	3·135	3·023	2·919	2·822	2·733	2·650
42	4·882	4·602	4·355	4·133	3·934	3·755	3·592	3·444	3·308	3·184	3·070	2·964	2·866	2·776	2·691
43	4·961	4·677	4·425	4·200	3·998	3·815	3·650	3·499	3·362	3·235	3·119	3·012	2·912	2·820	2·735
44	5·043	4·755	4·499	4·270	4·065	3·879	3·711	3·558	3·418	3·289	3·171	3·062	2·961	2·867	2·780
45	5·131	4·837	4·576	4·344	4·135	3·946	3·775	3·619	3·477	3·346	3·226	3·115	3·012	2·917	2·828
46	5·223	4·924	4·659	4·422	4·209	4·017	3·843	3·684	3·539	3·406	3·284	3·171	3·066	2·969	2·879
47	5·320	5·015	4·745	4·504	4·287	4·092	3·914	3·753	3·605	3·470	3·345	3·230	3·123	3·024	2·933
48	5·422	5·112	4·836	4·590	4·370	4·170	3·989	3·825	3·674	3·536	3·409	3·292	3·183	3·083	2·989
49	5·530	5·213	4·933	4·682	4·457	4·253	4·069	3·901	3·748	3·607	3·477	3·357	3·247	3·144	3·049
50	5·644	5·321	5·034	4·778	4·549	4·344	4·153	3·982	3·825	3·681	3·549	3·427	3·314	3·209	3·111
51	5·765	5·435	5·142	4·881	4·646	4·434	4·242	4·067	3·907	3·760	3·625	3·500	3·385	3·278	3·178
52	5·893	5·555	5·256	4·989	4·749	4·532	4·336	4·157	3·993	3·843	3·705	3·578	3·460	3·350	3·249
53	6·028	5·683	5·377	5·104	4·858	4·637	4·436	4·253	4·085	3·932	3·790	3·660	3·539	3·427	3·323
54	6·172	5·819	5·506	5·226	4·974	4·747	4·542	4·354	4·183	4·026	3·881	3·747	3·624	3·509	3·403
55	6·325	5·963	5·642	5·355	5·097	4·865	4·654	4·462	4·286	4·125	3·977	3·840	3·714	3·596	3·487
56	6·488	6·117	5·787	5·493	5·229	4·990	4·774	4·577	4·397	4·231	4·079	3·939	3·809	3·689	3·577
57	6·661	6·280	5·942	5·640	5·368	5·123	4·901	4·699	4·514	4·345	4·188	4·044	3·911	3·787	3·672
58	6·846	6·454	6·107	5·796	5·517	5·266	5·037	4·830	4·640	4·465	4·305	4·157	4·020	3·892	3·774
59	7·044	6·641	6·283	5·964	5·677	5·418	5·183	4·969	4·774	4·594	4·429	4·277	4·136	4·005	3·883
60	7·256	6·841	6·472	6·143	5·848	5·581	5·339	5·119	4·917	4·732	4·562	4·405	4·260	4·125	4·000

To convert into Time, multiply by 4. Thus, 7′·256 × 4 = 29s·024.
This applies also to the quantities in Table C.

TABLE D.

Shewing the error produced in the Longitude by an error of 1′ in the Altitude.

Lat.	TRUE AZIMUTH.														
	31°	32°	33°	34°	35°	36°	37°	38°	39°	40°	41°	42°	43°	44°	45°
0°	1·942	1·887	1·836	1·788	1·743	1·701	1·662	1·624	1·589	1·556	1·524	1·494	1·466	1·440	1·414
1	1·942	1·887	1·836	1·789	1·744	1·702	1·662	1·625	1·589	1·556	1·524	1·495	1·467	1·440	1·414
2	1·943	1·888	1·837	1·789	1·745	1·702	1·663	1·625	1·590	1·557	1·525	1·495	1·467	1·440	1·415
3	1·944	1·890	1·839	1·791	1·746	1·704	1·664	1·626	1·591	1·558	1·526	1·497	1·468	1·442	1·416
4	1·946	1·892	1·841	1·793	1·748	1·705	1·666	1·628	1·593	1·560	1·528	1·498	1·470	1·443	1·418
5	1·949	1·894	1·843	1·795	1·750	1·708	1·668	1·630	1·595	1·562	1·530	1·500	1·472	1·445	1·420
6°	1·952	1·897	1·846	1·798	1·753	1·711	1·671	1·633	1·598	1·564	1·533	1·503	1·474	1·447	1·422
7	1·956	1·901	1·850	1·802	1·757	1·714	1·674	1·636	1·601	1·567	1·536	1·506	1·477	1·450	1·425
8	1·961	1·906	1·854	1·806	1·761	1·718	1·678	1·640	1·605	1·571	1·539	1·509	1·481	1·454	1·428
9	1·966	1·911	1·859	1·811	1·765	1·723	1·682	1·645	1·609	1·575	1·543	1·513	1·485	1·458	1·432
10	1·972	1·916	1·864	1·816	1·770	1·728	1·687	1·649	1·614	1·580	1·548	1·518	1·489	1·462	1·436
11°	1·978	1·922	1·870	1·822	1·776	1·733	1·693	1·655	1·619	1·585	1·553	1·522	1·494	1·467	1·441
12	1·985	1·929	1·877	1·828	1·782	1·739	1·699	1·661	1·625	1·590	1·558	1·528	1·499	1·472	1·446
13	1·993	1·937	1·884	1·835	1·789	1·746	1·705	1·667	1·631	1·597	1·564	1·534	1·505	1·477	1·451
14	2·001	1·945	1·892	1·843	1·797	1·753	1·713	1·674	1·638	1·603	1·571	1·540	1·511	1·484	1·458
15	2·010	1·954	1·901	1·851	1·805	1·761	1·720	1·682	1·645	1·611	1·578	1·547	1·518	1·490	1·464
16°	2·020	1·963	1·910	1·860	1·814	1·770	1·729	1·690	1·653	1·618	1·586	1·555	1·525	1·498	1·471
17	2·030	1·973	1·920	1·870	1·823	1·779	1·738	1·698	1·662	1·627	1·594	1·563	1·533	1·505	1·479
18	2·042	1·984	1·931	1·880	1·833	1·789	1·747	1·708	1·671	1·636	1·603	1·571	1·542	1·514	1·487
19	2·053	1·996	1·942	1·891	1·844	1·799	1·757	1·718	1·681	1·645	1·612	1·581	1·551	1·523	1·496
20	2·066	2·008	1·954	1·903	1·855	1·810	1·768	1·729	1·691	1·656	1·622	1·590	1·560	1·532	1·505
21°	2·080	2·021	1·967	1·916	1·867	1·822	1·780	1·740	1·702	1·666	1·633	1·601	1·571	1·542	1·515
22	2·094	2·035	1·980	1·929	1·880	1·835	1·792	1·752	1·714	1·678	1·644	1·612	1·581	1·553	1·525
23	2·109	2·050	1·995	1·943	1·894	1·848	1·805	1·765	1·726	1·690	1·656	1·624	1·593	1·564	1·536
24	2·125	2·066	2·010	1·958	1·908	1·862	1·819	1·778	1·739	1·703	1·669	1·636	1·605	1·576	1·548
25	2·142	2·082	2·026	1·973	1·924	1·877	1·833	1·792	1·753	1·717	1·682	1·649	1·618	1·588	1·560
26°	2·160	2·100	2·043	1·990	1·940	1·893	1·849	1·807	1·768	1·731	1·696	1·663	1·631	1·602	1·573
27	2·179	2·118	2·061	2·007	1·957	1·909	1·865	1·823	1·783	1·746	1·711	1·677	1·646	1·616	1·587
28	2·199	2·137	2·079	2·025	1·975	1·927	1·882	1·840	1·800	1·762	1·726	1·693	1·661	1·630	1·602
29	2·220	2·158	2·099	2·045	1·993	1·945	1·900	1·857	1·817	1·779	1·743	1·709	1·676	1·646	1·617
30	2·242	2·179	2·120	2·065	2·013	1·964	1·919	1·876	1·835	1·796	1·760	1·726	1·693	1·662	1·633
31°	2·265	2·202	2·142	2·086	2·034	1·985	1·939	1·895	1·854	1·815	1·778	1·744	1·711	1·679	1·650
32	2·289	2·225	2·165	2·109	2·056	2·006	1·959	1·915	1·874	1·834	1·797	1·762	1·729	1·697	1·668
33	2·315	2·250	2·189	2·132	2·079	2·029	1·981	1·937	1·895	1·855	1·817	1·782	1·748	1·716	1·686
34	2·342	2·276	2·215	2·157	2·103	2·052	2·004	1·959	1·917	1·877	1·839	1·803	1·769	1·736	1·706
35	2·370	2·304	2·241	2·183	2·128	2·077	2·028	1·983	1·940	1·899	1·861	1·824	1·790	1·757	1·726
36°	2·400	2·333	2·270	2·210	2·155	2·103	2·054	2·008	1·964	1·923	1·884	1·847	1·812	1·779	1·748
37	2·431	2·363	2·299	2·239	2·183	2·130	2·081	2·034	1·990	1·948	1·909	1·871	1·836	1·803	1·771
38	2·464	2·395	2·330	2·269	2·212	2·159	2·109	2·061	2·016	1·974	1·934	1·897	1·861	1·827	1·795
39	2·498	2·428	2·363	2·301	2·243	2·189	2·138	2·090	2·045	2·002	1·961	1·923	1·887	1·852	1·820
40	2·535	2·463	2·397	2·334	2·276	2·221	2·169	2·120	2·074	2·031	1·990	1·951	1·914	1·879	1·846
41°	2·573	2·500	2·433	2·370	2·310	2·254	2·202	2·152	2·105	2·061	2·020	1·980	1·943	1·907	1·874
42	2·613	2·539	2·471	2·406	2·346	2·289	2·236	2·186	2·138	2·093	2·051	2·011	1·973	1·937	1·903
43	2·655	2·580	2·511	2·445	2·384	2·326	2·272	2·221	2·173	2·127	2·084	2·043	2·005	1·968	1·934
44	2·699	2·623	2·552	2·486	2·424	2·365	2·310	2·258	2·209	2·163	2·119	2·078	2·038	2·001	1·966
45	2·746	2·669	2·597	2·529	2·466	2·406	2·350	2·297	2·247	2·200	2·156	2·114	2·074	2·036	2·000
46°	2·795	2·717	2·643	2·574	2·510	2·449	2·392	2·338	2·287	2·240	2·194	2·151	2·111	2·072	2·036
47	2·847	2·767	2·692	2·622	2·556	2·495	2·436	2·382	2·330	2·281	2·235	2·191	2·150	2·111	2·074
48	2·902	2·820	2·744	2·673	2·606	2·543	2·483	2·427	2·375	2·325	2·278	2·233	2·191	2·151	2·114
49	2·959	2·876	2·799	2·726	2·657	2·593	2·533	2·476	2·422	2·371	2·323	2·278	2·235	2·194	2·156
50	3·021	2·936	2·856	2·782	2·712	2·647	2·585	2·527	2·472	2·420	2·371	2·325	2·281	2·240	2·200
51°	3·085	2·999	2·918	2·842	2·770	2·703	2·640	2·581	2·525	2·472	2·422	2·375	2·330	2·287	2·247
52	3·154	3·065	2·982	2·905	2·832	2·763	2·699	2·638	2·581	2·527	2·476	2·427	2·382	2·338	2·297
53	3·226	3·136	3·051	2·971	2·897	2·827	2·761	2·699	2·640	2·585	2·533	2·483	2·436	2·392	2·350
54	3·303	3·210	3·124	3·042	2·966	2·894	2·827	2·763	2·703	2·647	2·593	2·543	2·495	2·449	2·406
55	3·385	3·290	3·201	3·118	3·040	2·966	2·897	2·832	2·770	2·712	2·657	2·606	2·556	2·510	2·466
56°	3·472	3·375	3·283	3·198	3·118	3·042	2·971	2·905	2·842	2·782	2·726	2·673	2·622	2·574	2·529
57	3·565	3·465	3·371	3·283	3·201	3·124	3·051	2·982	2·918	2·856	2·799	2·744	2·692	2·643	2·597
58	3·664	3·561	3·465	3·375	3·290	3·210	3·136	3·065	2·999	2·936	2·876	2·820	2·767	2·717	2·669
59	3·770	3·664	3·565	3·472	3·385	3·303	3·226	3·154	3·085	3·021	2·959	2·902	2·847	2·795	2·746
60	3·883	3·774	3·672	3·577	3·487	3·403	3·323	3·249	3·178	3·111	3·049	2·989	2·933	2·879	2·828

To convert into Time, multiply by 4. Thus 3′·883 × 4 = 15ˢ·532.
This applies also to the quantities in Table C

TABLE D.

Shewing the error produced in the Longitude by an error of 1′ in the Altitude.

Lat.	TRUE AZIMUTH.														
	46°	47°	48°	49°	50°	51°	52°	53°	54°	55°	56°	57°	58°	59°	60°
0°	1·390	1·367	1·346	1·325	1·305	1·287	1·269	1·252	1·236	1·221	1·206	1·192	1·179	1·167	1·155
1	1·390	1·368	1·346	1·325	1·306	1·287	1·269	1·252	1·236	1·221	1·206	1·193	1·179	1·167	1·155
2	1·391	1·368	1·346	1·326	1·306	1·288	1·270	1·253	1·237	1·222	1·207	1·193	1·180	1·167	1·155
3	1·392	1·369	1·347	1·327	1·307	1·289	1·271	1·254	1·238	1·222	1·208	1·194	1·181	1·168	1·156
4	1·394	1·371	1·349	1·328	1·309	1·290	1·272	1·255	1·239	1·224	1·209	1·195	1·182	1·169	1·158
5	1·395	1·373	1·351	1·330	1·310	1·292	1·274	1·257	1·241	1·225	1·211	1·197	1·184	1·171	1·159
6°	1·398	1·375	1·353	1·332	1·313	1·294	1·276	1·259	1·243	1·227	1·213	1·199	1·186	1·173	1·161
7	1·401	1·378	1·356	1·335	1·315	1·296	1·279	1·262	1·245	1·230	1·215	1·201	1·188	1·175	1·163
8	1·404	1·381	1·359	1·338	1·318	1·299	1·281	1·264	1·248	1·233	1·218	1·204	1·191	1·178	1·166
9	1·407	1·384	1·362	1·342	1·322	1·303	1·285	1·268	1·251	1·236	1·221	1·207	1·194	1·181	1·169
10	1·412	1·388	1·366	1·345	1·326	1·307	1·289	1·271	1·255	1·240	1·225	1·211	1·197	1·185	1·173
11°	1·416	1·393	1·371	1·350	1·330	1·311	1·293	1·276	1·259	1·244	1·229	1·215	1·201	1·188	1·176
12	1·421	1·398	1·376	1·355	1·335	1·316	1·297	1·280	1·264	1·248	1·233	1·219	1·206	1·193	1·180
13	1·427	1·403	1·381	1·360	1·340	1·321	1·302	1·285	1·269	1·253	1·238	1·224	1·210	1·197	1·185
14	1·433	1·409	1·387	1·366	1·345	1·326	1·308	1·290	1·274	1·258	1·243	1·229	1·215	1·202	1·190
15	1·439	1·416	1·393	1·372	1·351	1·332	1·314	1·296	1·280	1·264	1·249	1·234	1·221	1·208	1·195
16°	1·446	1·422	1·400	1·378	1·358	1·339	1·320	1·303	1·286	1·270	1·255	1·240	1·227	1·214	1·201
17	1·454	1·430	1·407	1·386	1·365	1·346	1·327	1·309	1·293	1·277	1·261	1·247	1·233	1·220	1·207
18	1·462	1·438	1·415	1·393	1·373	1·353	1·334	1·317	1·300	1·284	1·268	1·254	1·240	1·227	1·214
19	1·470	1·446	1·423	1·401	1·381	1·361	1·342	1·324	1·307	1·291	1·276	1·261	1·247	1·234	1·221
20	1·479	1·455	1·432	1·410	1·389	1·369	1·350	1·332	1·315	1·299	1·284	1·269	1·255	1·242	1·229
21°	1·489	1·465	1·441	1·419	1·398	1·378	1·359	1·341	1·324	1·308	1·292	1·277	1·263	1·250	1·237
22	1·499	1·475	1·451	1·429	1·408	1·388	1·369	1·350	1·333	1·317	1·301	1·286	1·272	1·258	1·245
23	1·510	1·485	1·462	1·439	1·418	1·398	1·379	1·360	1·343	1·326	1·310	1·295	1·281	1·267	1·254
24	1·522	1·497	1·473	1·450	1·429	1·409	1·389	1·371	1·353	1·336	1·320	1·305	1·291	1·277	1·264
25	1·534	1·509	1·485	1·462	1·440	1·420	1·400	1·382	1·364	1·347	1·331	1·316	1·301	1·287	1·274
26°	1·547	1·521	1·497	1·474	1·452	1·432	1·412	1·393	1·375	1·358	1·342	1·327	1·312	1·298	1·285
27	1·560	1·535	1·510	1·487	1·465	1·444	1·424	1·405	1·387	1·370	1·354	1·338	1·323	1·309	1·296
28	1·574	1·549	1·524	1·501	1·478	1·457	1·437	1·418	1·400	1·383	1·366	1·350	1·336	1·321	1·308
29	1·589	1·563	1·539	1·515	1·493	1·471	1·451	1·432	1·413	1·396	1·379	1·363	1·348	1·334	1·320
30	1·605	1·579	1·554	1·530	1·507	1·486	1·465	1·446	1·427	1·410	1·393	1·377	1·362	1·347	1·333
31°	1·622	1·595	1·570	1·546	1·523	1·501	1·480	1·461	1·442	1·424	1·407	1·391	1·376	1·361	1·347
32	1·639	1·612	1·587	1·562	1·539	1·517	1·496	1·476	1·458	1·440	1·422	1·406	1·390	1·376	1·362
33	1·658	1·630	1·604	1·580	1·557	1·534	1·513	1·493	1·474	1·456	1·438	1·422	1·406	1·391	1·377
34	1·677	1·649	1·623	1·598	1·575	1·552	1·531	1·510	1·491	1·473	1·455	1·438	1·422	1·407	1·393
35	1·697	1·669	1·643	1·618	1·594	1·571	1·549	1·529	1·509	1·490	1·473	1·456	1·440	1·424	1·410
36°	1·718	1·690	1·663	1·638	1·614	1·591	1·569	1·548	1·528	1·509	1·491	1·474	1·458	1·442	1·427
37	1·741	1·712	1·685	1·659	1·635	1·611	1·589	1·568	1·548	1·529	1·510	1·493	1·476	1·461	1·446
38	1·764	1·735	1·708	1·681	1·657	1·633	1·610	1·589	1·569	1·549	1·531	1·513	1·496	1·480	1·465
39	1·789	1·759	1·732	1·705	1·680	1·656	1·633	1·611	1·591	1·571	1·552	1·534	1·517	1·501	1·486
40	1·815	1·785	1·757	1·730	1·704	1·680	1·657	1·635	1·614	1·594	1·575	1·557	1·539	1·523	1·507
41°	1·842	1·812	1·783	1·756	1·730	1·705	1·681	1·659	1·638	1·618	1·598	1·580	1·562	1·546	1·530
42	1·871	1·840	1·811	1·783	1·757	1·732	1·708	1·685	1·663	1·643	1·623	1·604	1·587	1·570	1·554
43	1·901	1·870	1·840	1·812	1·785	1·759	1·735	1·712	1·690	1·669	1·649	1·630	1·612	1·595	1·579
44	1·933	1·901	1·871	1·842	1·815	1·789	1·764	1·741	1·718	1·697	1·677	1·658	1·639	1·622	1·605
45	1·966	1·934	1·903	1·874	1·846	1·820	1·795	1·771	1·748	1·726	1·706	1·686	1·668	1·650	1·633
46°	2·001	1·968	1·937	1·907	1·879	1·852	1·827	1·803	1·779	1·757	1·736	1·716	1·697	1·679	1·662
47	2·038	2·005	1·973	1·943	1·914	1·887	1·861	1·836	1·812	1·790	1·769	1·748	1·729	1·711	1·693
48	2·078	2·043	2·011	1·980	1·951	1·923	1·897	1·871	1·847	1·824	1·803	1·782	1·762	1·744	1·726
49	2·119	2·084	2·051	2·020	1·990	1·961	1·934	1·909	1·884	1·861	1·839	1·817	1·797	1·778	1·760
50	2·163	2·127	2·093	2·061	2·031	2·002	1·974	1·948	1·923	1·899	1·877	1·855	1·834	1·815	1·796
51°	2·209	2·173	2·138	2·105	2·074	2·045	2·016	1·990	1·964	1·940	1·917	1·895	1·874	1·854	1·835
52	2·258	2·221	2·186	2·152	2·120	2·090	2·061	2·034	2·008	1·983	1·959	1·937	1·915	1·895	1·876
53	2·310	2·272	2·236	2·202	2·169	2·138	2·109	2·081	2·054	2·028	2·004	1·981	1·959	1·939	1·919
54	2·365	2·326	2·289	2·254	2·221	2·189	2·159	2·130	2·103	2·077	2·052	2·029	2·006	1·985	1·964
55	2·424	2·384	2·346	2·310	2·276	2·243	2·212	2·183	2·155	2·128	2·103	2·079	2·056	2·034	2·013
56°	2·486	2·445	2·406	2·370	2·334	2·301	2·269	2·239	2·210	2·183	2·157	2·132	2·109	2·086	2·065
57	2·552	2·511	2·471	2·433	2·397	2·363	2·330	2·299	2·270	2·241	2·215	2·189	2·165	2·142	2·120
58	2·623	2·580	2·539	2·500	2·463	2·428	2·395	2·363	2·333	2·304	2·276	2·250	2·225	2·202	2·179
59	2·699	2·655	2·613	2·573	2·535	2·498	2·464	2·431	2·400	2·370	2·342	2·315	2·289	2·265	2·242
60	2·780	2·735	2·691	2·650	2·611	2·574	2·538	2·504	2·472	2·442	2·412	2·385	2·358	2·333	2·309

To convert into Time, multiply by 4. Thus, 2′·780 × 4 = 11ˢ·120.
This applies also to the quantities in Table C.

TABLE D.

Shewing the error produced in the Longitude by an error of 1′ in the Altitude.

Lat.	TRUE AZIMUTH.														
	31°	32°	33°	34°	35°	36°	37°	38°	39°	40°	41°	42°	43°	44°	45°
0°	1·942	1·887	1·836	1·788	1·743	1·701	1·662	1·624	1·589	1·556	1·524	1·494	1·466	1·440	1·414
1	1·942	1·887	1·836	1·789	1·744	1·702	1·662	1·625	1·589	1·556	1·524	1·495	1·467	1·440	1·414
2	1·943	1·888	1·837	1·789	1·745	1·702	1·663	1·625	1·590	1·557	1·525	1·495	1·467	1·440	1·415
3	1·944	1·890	1·839	1·791	1·746	1·704	1·664	1·626	1·591	1·558	1·526	1·497	1·468	1·442	1·416
4	1·946	1·892	1·841	1·793	1·748	1·705	1·666	1·628	1·593	1·560	1·528	1·498	1·470	1·443	1·418
5	1·949	1·894	1·843	1·795	1·750	1·708	1·668	1·630	1·595	1·562	1·530	1·500	1·472	1·445	1·420
6°	1·952	1·897	1·846	1·798	1·753	1·711	1·671	1·633	1·598	1·564	1·533	1·503	1·474	1·447	1·422
7	1·956	1·901	1·850	1·802	1·757	1·714	1·674	1·636	1·601	1·567	1·536	1·506	1·477	1·450	1·425
8	1·961	1·906	1·854	1·806	1·761	1·718	1·678	1·640	1·605	1·571	1·539	1·509	1·481	1·454	1·428
9	1·966	1·911	1·859	1·811	1·765	1·723	1·682	1·645	1·609	1·575	1·543	1·513	1·485	1·458	1·432
10	1·972	1·916	1·864	1·816	1·770	1·728	1·687	1·649	1·614	1·580	1·548	1·518	1·489	1·462	1·436
11°	1·978	1·922	1·870	1·822	1·776	1·733	1·693	1·655	1·619	1·585	1·553	1·522	1·494	1·467	1·441
12	1·985	1·929	1·877	1·828	1·782	1·739	1·699	1·661	1·625	1·590	1·558	1·528	1·499	1·472	1·446
13	1·993	1·937	1·884	1·835	1·789	1·746	1·705	1·667	1·631	1·597	1·564	1·534	1·505	1·477	1·451
14	2·001	1·945	1·892	1·843	1·797	1·753	1·713	1·674	1·638	1·603	1·571	1·540	1·511	1·484	1·458
15	2·010	1·954	1·901	1·851	1·805	1·761	1·720	1·682	1·645	1·611	1·578	1·547	1·518	1·490	1·464
16°	2·020	1·963	1·910	1·860	1·814	1·770	1·729	1·690	1·653	1·618	1·586	1·555	1·525	1·498	1·471
17	2·030	1·973	1·920	1·870	1·823	1·779	1·738	1·698	1·662	1·627	1·594	1·563	1·533	1·505	1·479
18	2·042	1·984	1·931	1·880	1·833	1·789	1·747	1·708	1·671	1·636	1·603	1·571	1·542	1·514	1·487
19	2·053	1·996	1·942	1·891	1·844	1·799	1·757	1·718	1·681	1·645	1·612	1·581	1·551	1·523	1·496
20	2·066	2·008	1·954	1·903	1·855	1·810	1·768	1·729	1·691	1·656	1·622	1·590	1·560	1·532	1·505
21°	2·080	2·021	1·967	1·916	1·867	1·822	1·780	1·740	1·702	1·666	1·633	1·601	1·571	1·542	1·515
22	2·094	2·035	1·980	1·929	1·880	1·835	1·792	1·752	1·714	1·678	1·644	1·612	1·581	1·553	1·525
23	2·109	2·050	1·995	1·943	1·894	1·848	1·805	1·765	1·726	1·690	1·656	1·624	1·593	1·564	1·536
24	2·125	2·066	2·010	1·958	1·908	1·862	1·819	1·778	1·739	1·703	1·669	1·636	1·605	1·576	1·548
25	2·142	2·082	2·026	1·973	1·924	1·877	1·833	1·792	1·753	1·717	1·682	1·649	1·618	1·588	1·560
26°	2·160	2·100	2·043	1·990	1·940	1·893	1·849	1·807	1·768	1·731	1·696	1·663	1·631	1·602	1·573
27	2·179	2·118	2·061	2·007	1·957	1·909	1·865	1·823	1·783	1·746	1·711	1·677	1·646	1·616	1·587
28	2·199	2·137	2·079	2·025	1·975	1·927	1·882	1·840	1·800	1·762	1·726	1·693	1·661	1·630	1·602
29	2·220	2·158	2·099	2·045	1·993	1·945	1·900	1·857	1·817	1·779	1·743	1·709	1·676	1·646	1·617
30	2·242	2·179	2·120	2·065	2·013	1·964	1·919	1·876	1·835	1·796	1·760	1·725	1·693	1·662	1·633
31°	2·265	2·202	2·142	2·086	2·034	1·985	1·939	1·895	1·854	1·815	1·778	1·744	1·711	1·679	1·650
32	2·289	2·225	2·165	2·109	2·056	2·006	1·959	1·915	1·874	1·834	1·797	1·762	1·729	1·697	1·668
33	2·315	2·250	2·189	2·132	2·079	2·029	1·981	1·937	1·895	1·855	1·817	1·782	1·748	1·716	1·686
34	2·342	2·276	2·215	2·157	2·103	2·052	2·004	1·959	1·917	1·877	1·839	1·803	1·769	1·736	1·706
35	2·370	2·304	2·241	2·183	2·128	2·077	2·028	1·983	1·940	1·899	1·861	1·824	1·790	1·757	1·726
36°	2·400	2·333	2·270	2·210	2·155	2·103	2·054	2·008	1·964	1·923	1·884	1·847	1·812	1·779	1·748
37	2·431	2·363	2·299	2·239	2·183	2·130	2·081	2·034	1·990	1·948	1·909	1·871	1·836	1·803	1·771
38	2·464	2·395	2·330	2·269	2·212	2·159	2·109	2·061	2·016	1·974	1·934	1·897	1·861	1·827	1·795
39	2·498	2·428	2·363	2·301	2·243	2·189	2·138	2·090	2·045	2·002	1·961	1·923	1·887	1·852	1·820
40	2·535	2·463	2·397	2·334	2·276	2·221	2·169	2·120	2·074	2·031	1·990	1·951	1·914	1·879	1·846
41°	2·573	2·500	2·433	2·370	2·310	2·254	2·202	2·152	2·105	2·061	2·020	1·980	1·943	1·907	1·874
42	2·613	2·539	2·471	2·406	2·346	2·289	2·236	2·186	2·138	2·093	2·051	2·011	1·973	1·937	1·903
43	2·655	2·580	2·511	2·445	2·384	2·326	2·272	2·221	2·173	2·127	2·084	2·043	2·005	1·968	1·934
44	2·699	2·623	2·552	2·486	2·424	2·365	2·310	2·258	2·209	2·163	2·119	2·078	2·038	2·001	1·966
45	2·746	2·669	2·597	2·529	2·466	2·406	2·350	2·297	2·247	2·200	2·156	2·114	2·074	2·036	2·000
46°	2·795	2·717	2·643	2·574	2·510	2·449	2·392	2·338	2·287	2·240	2·194	2·151	2·111	2·072	2·036
47	2·847	2·767	2·692	2·622	2·556	2·495	2·436	2·382	2·330	2·281	2·235	2·191	2·150	2·111	2·074
48	2·902	2·820	2·744	2·673	2·606	2·543	2·483	2·427	2·375	2·325	2·278	2·233	2·191	2·151	2·114
49	2·959	2·876	2·799	2·726	2·657	2·593	2·533	2·476	2·422	2·371	2·323	2·278	2·235	2·194	2·156
50	3·021	2·936	2·856	2·782	2·712	2·647	2·585	2·527	2·472	2·420	2·371	2·325	2·281	2·240	2·200
51°	3·085	2·999	2·918	2·842	2·770	2·703	2·640	2·581	2·525	2·472	2·422	2·375	2·330	2·287	2·247
52	3·154	3·065	2·982	2·905	2·832	2·763	2·699	2·638	2·581	2·527	2·476	2·427	2·382	2·338	2·297
53	3·226	3·136	3·051	2·971	2·897	2·827	2·761	2·699	2·640	2·585	2·533	2·483	2·436	2·392	2·350
54	3·303	3·210	3·124	3·042	2·966	2·894	2·827	2·763	2·703	2·647	2·593	2·543	2·495	2·449	2·406
55	3·385	3·290	3·201	3·118	3·040	2·966	2·897	2·832	2·770	2·712	2·657	2·606	2·556	2·510	2·466
56°	3·472	3·375	3·283	3·198	3·118	3·042	2·971	2·905	2·842	2·782	2·726	2·673	2·622	2·574	2·529
57	3·565	3·465	3·371	3·283	3·201	3·124	3·051	2·982	2·918	2·856	2·799	2·744	2·692	2·643	2·597
58	3·664	3·561	3·465	3·375	3·290	3·210	3·136	3·065	2·999	2·936	2·876	2·820	2·767	2·717	2·669
59	3·770	3·664	3·565	3·472	3·385	3·303	3·226	3·154	3·085	3·021	2·959	2·902	2·847	2·795	2·746
60	3·883	3·774	3·672	3·577	3·487	3·403	3·323	3·249	3·178	3·111	3·049	2·989	2·933	2·879	2·828

To convert into Time, multiply by 4. Thus $3'{\cdot}883 \times 4 = 15^{s}{\cdot}532$.
This applies also to the quantities in Table C

TABLE D.

Shewing the error produced in the Longitude by an error of 1′ in the Altitude.

Lat.	46°	47°	48°	49°	50°	51°	52°	53°	54°	55°	56°	57°	58°	59°	60°
° 0	1·390	1·367	1·346	1·325	1·305	1·287	1·269	1·252	1·236	1·221	1·206	1·192	1·179	1·167	1·155
1	1·390	1·368	1·346	1·325	1·306	1·287	1·269	1·252	1·236	1·221	1·206	1·193	1·179	1·167	1·155
2	1·391	1·368	1·346	1·326	1·306	1·288	1·270	1·253	1·237	1·222	1·207	1·193	1·180	1·167	1·155
3	1·392	1·369	1·347	1·327	1·307	1·289	1·271	1·254	1·238	1·222	1·208	1·194	1·181	1·168	1·156
4	1·394	1·371	1·349	1·328	1·309	1·290	1·272	1·255	1·239	1·224	1·209	1·195	1·182	1·169	1·158
5	1·395	1·373	1·351	1·330	1·310	1·292	1·274	1·257	1·241	1·225	1·211	1·197	1·184	1·171	1·159
6	1·398	1·375	1·353	1·332	1·313	1·294	1·276	1·259	1·243	1·227	1·213	1·199	1·186	1·173	1·161
7	1·401	1·378	1·356	1·335	1·315	1·296	1·279	1·262	1·245	1·230	1·215	1·201	1·188	1·175	1·163
8	1·404	1·381	1·359	1·338	1·318	1·299	1·281	1·264	1·248	1·233	1·218	1·204	1·191	1·178	1·166
9	1·407	1·384	1·362	1·342	1·322	1·303	1·285	1·268	1·251	1·236	1·221	1·207	1·194	1·181	1·169
10	1·412	1·388	1·366	1·345	1·326	1·307	1·289	1·271	1·255	1·240	1·225	1·211	1·197	1·185	1·173
11	1·416	1·393	1·371	1·350	1·330	1·311	1·293	1·276	1·259	1·244	1·229	1·215	1·201	1·188	1·176
12	1·421	1·398	1·376	1·355	1·335	1·316	1·297	1·280	1·264	1·248	1·233	1·219	1·206	1·193	1·180
13	1·427	1·403	1·381	1·360	1·340	1·321	1·302	1·285	1·269	1·253	1·238	1·224	1·210	1·197	1·185
14	1·433	1·409	1·387	1·366	1·345	1·326	1·308	1·290	1·274	1·258	1·243	1·229	1·215	1·202	1·190
15	1·439	1·416	1·393	1·372	1·351	1·332	1·314	1·296	1·280	1·264	1·249	1·234	1·221	1·208	1·195
16	1·446	1·422	1·400	1·378	1·358	1·339	1·320	1·303	1·286	1·270	1·255	1·240	1·227	1·214	1·201
17	1·454	1·430	1·407	1·386	1·365	1·346	1·327	1·309	1·293	1·277	1·261	1·247	1·233	1·220	1·207
18	1·462	1·438	1·415	1·393	1·373	1·353	1·334	1·317	1·300	1·284	1·268	1·254	1·240	1·227	1·214
19	1·470	1·446	1·423	1·401	1·381	1·361	1·342	1·324	1·307	1·291	1·276	1·261	1·247	1·234	1·221
20	1·479	1·455	1·432	1·410	1·389	1·369	1·350	1·332	1·315	1·299	1·284	1·269	1·255	1·242	1·229
21	1·489	1·465	1·441	1·419	1·398	1·378	1·359	1·341	1·324	1·308	1·292	1·277	1·263	1·250	1·237
22	1·499	1·475	1·451	1·429	1·408	1·388	1·369	1·350	1·333	1·317	1·301	1·286	1·272	1·258	1·245
23	1·510	1·485	1·462	1·439	1·418	1·398	1·379	1·360	1·343	1·326	1·310	1·295	1·281	1·267	1·254
24	1·522	1·497	1·473	1·450	1·429	1·409	1·389	1·371	1·353	1·336	1·320	1·305	1·291	1·277	1·264
25	1·534	1·509	1·485	1·462	1·440	1·420	1·400	1·382	1·364	1·347	1·331	1·316	1·301	1·287	1·274
26	1·547	1·521	1·497	1·474	1·452	1·432	1·412	1·393	1·375	1·358	1·342	1·327	1·312	1·298	1·285
27	1·560	1·535	1·510	1·487	1·465	1·444	1·424	1·405	1·387	1·370	1·354	1·338	1·323	1·309	1·296
28	1·574	1·549	1·524	1·501	1·478	1·457	1·437	1·418	1·400	1·383	1·366	1·350	1·336	1·321	1·308
29	1·589	1·563	1·539	1·515	1·493	1·471	1·451	1·432	1·413	1·396	1·379	1·363	1·348	1·334	1·320
30	1·605	1·579	1·554	1·530	1·507	1·486	1·465	1·446	1·427	1·410	1·393	1·377	1·362	1·347	1·333
31	1·622	1·595	1·570	1·546	1·523	1·501	1·480	1·461	1·442	1·424	1·407	1·391	1·376	1·361	1·347
32	1·639	1·612	1·587	1·562	1·539	1·517	1·496	1·476	1·458	1·440	1·422	1·406	1·390	1·376	1·362
33	1·658	1·630	1·604	1·580	1·557	1·534	1·513	1·493	1·474	1·456	1·438	1·422	1·406	1·391	1·377
34	1·677	1·649	1·623	1·598	1·575	1·552	1·531	1·510	1·491	1·473	1·455	1·438	1·422	1·407	1·393
35	1·697	1·669	1·643	1·618	1·594	1·571	1·549	1·529	1·509	1·490	1·473	1·456	1·440	1·424	1·410
36	1·718	1·690	1·663	1·638	1·614	1·591	1·569	1·548	1·528	1·509	1·491	1·474	1·458	1·442	1·427
37	1·741	1·712	1·685	1·659	1·635	1·611	1·589	1·568	1·548	1·529	1·510	1·493	1·476	1·461	1·446
38	1·764	1·735	1·708	1·681	1·657	1·633	1·610	1·589	1·569	1·549	1·531	1·513	1·496	1·480	1·465
39	1·789	1·759	1·732	1·705	1·680	1·656	1·633	1·611	1·591	1·571	1·552	1·534	1·517	1·501	1·486
40	1·815	1·785	1·757	1·730	1·704	1·680	1·657	1·635	1·614	1·594	1·575	1·557	1·539	1·523	1·507
41	1·842	1·812	1·783	1·756	1·730	1·705	1·681	1·659	1·638	1·618	1·598	1·580	1·562	1·546	1·530
42	1·871	1·840	1·811	1·783	1·757	1·732	1·708	1·685	1·663	1·643	1·623	1·604	1·587	1·570	1·554
43	1·901	1·870	1·840	1·812	1·785	1·759	1·735	1·712	1·690	1·669	1·649	1·630	1·612	1·595	1·579
44	1·933	1·901	1·871	1·842	1·815	1·789	1·764	1·741	1·718	1·697	1·677	1·658	1·639	1·622	1·605
45	1·966	1·934	1·903	1·874	1·846	1·820	1·795	1·771	1·748	1·726	1·706	1·686	1·668	1·650	1·633
46	2·001	1·968	1·937	1·907	1·879	1·852	1·827	1·803	1·779	1·757	1·736	1·716	1·697	1·679	1·662
47	2·038	2·005	1·973	1·943	1·914	1·887	1·861	1·836	1·812	1·790	1·769	1·748	1·729	1·711	1·693
48	2·078	2·043	2·011	1·980	1·951	1·923	1·897	1·871	1·847	1·824	1·803	1·782	1·762	1·744	1·726
49	2·119	2·084	2·051	2·020	1·990	1·961	1·934	1·909	1·884	1·861	1·839	1·817	1·797	1·778	1·760
50	2·163	2·127	2·093	2·061	2·031	2·002	1·974	1·948	1·923	1·899	1·877	1·855	1·834	1·815	1·796
51	2·209	2·173	2·138	2·105	2·074	2·045	2·016	1·990	1·964	1·940	1·917	1·895	1·874	1·854	1·835
52	2·258	2·221	2·186	2·152	2·120	2·090	2·061	2·034	2·008	1·983	1·959	1·937	1·915	1·895	1·876
53	2·310	2·272	2·236	2·202	2·169	2·138	2·109	2·081	2·054	2·028	2·004	1·981	1·959	1·939	1·919
54	2·365	2·326	2·289	2·254	2·221	2·189	2·159	2·130	2·103	2·077	2·052	2·029	2·006	1·985	1·964
55	2·424	2·384	2·346	2·310	2·276	2·243	2·212	2·183	2·155	2·128	2·103	2·079	2·056	2·034	2·013
56	2·486	2·445	2·406	2·370	2·334	2·301	2·269	2·239	2·210	2·183	2·157	2·132	2·109	2·086	2·065
57	2·552	2·511	2·471	2·433	2·397	2·363	2·330	2·299	2·270	2·241	2·215	2·189	2·165	2·142	2·120
58	2·623	2·580	2·539	2·500	2·463	2·428	2·395	2·363	2·333	2·304	2·276	2·250	2·225	2·202	2·179
59	2·699	2·655	2·613	2·573	2·535	2·498	2·464	2·431	2·400	2·370	2·342	2·315	2·289	2·265	2·242
60	2·780	2·735	2·691	2·650	2·611	2·574	2·538	2·504	2·472	2·442	2·412	2·385	2·358	2·333	2·309

(Column heads 46°–60° stand under the common heading TRUE AZIMUTH.)

To convert into Time, multiply by 4. Thus, $2'780 \times 4 = 11^{s}\cdot120$.
This applies also to the quantities in Table C.

TABLE D.

Shewing the error produced in the Longitude by an error of 1′ in the Altitude.

Lat.	TRUE AZIMUTH.														
	61°	62°	63°	64°	65°	66°	67°	68°	69°	70°	71°	72°	73°	74°	75°
0°	1·143	1·133	1·122	1·113	1·103	1·095	1·086	1·079	1·071	1·064	1·058	1·051	1·046	1·040	1·035
1	1·144	1·133	1·122	1·113	1·104	1·095	1·087	1·079	1·071	1·064	1·058	1·052	1·046	1·040	1·035
2	1·144	1·133	1·123	1·113	1·104	1·095	1·087	1·079	1·072	1·065	1·058	1·052	1·046	1·041	1·036
3	1·145	1·134	1·124	1·114	1·105	1·096	1·088	1·080	1·073	1·066	1·059	1·053	1·047	1·042	1·037
4	1·146	1·135	1·125	1·115	1·106	1·097	1·089	1·081	1·074	1·067	1·060	1·054	1·048	1·043	1·038
5	1·148	1·137	1·127	1·117	1·108	1·099	1·091	1·083	1·075	1·068	1·062	1·055	1·050	1·044	1·039
6°	1·150	1·139	1·129	1·119	1·109	1·101	1·092	1·084	1·077	1·070	1·063	1·057	1·051	1·046	1·041
7	1·152	1·141	1·131	1·121	1·112	1·103	1·095	1·087	1·079	1·072	1·066	1·059	1·054	1·048	1·043
8	1·155	1·144	1·133	1·124	1·114	1·105	1·097	1·089	1·082	1·075	1·068	1·062	1·056	1·051	1·045
9	1·158	1·147	1·136	1·126	1·117	1·108	1·100	1·092	1·084	1·077	1·071	1·065	1·059	1·053	1·048
10	1·161	1·150	1·140	1·130	1·120	1·112	1·103	1·095	1·088	1·081	1·074	1·068	1·062	1·056	1·051
11°	1·165	1·154	1·143	1·133	1·124	1·115	1·107	1·099	1·091	1·084	1·077	1·071	1·065	1·060	1·055
12	1·169	1·158	1·147	1·137	1·128	1·119	1·111	1·103	1·095	1·088	1·081	1·075	1·069	1·064	1·058
13	1·173	1·162	1·152	1·142	1·132	1·123	1·115	1·107	1·099	1·092	1·085	1·079	1·073	1·068	1·063
14	1·178	1·167	1·157	1·147	1·137	1·128	1·120	1·112	1·104	1·097	1·090	1·084	1·078	1·072	1·067
15	1·184	1·173	1·162	1·152	1·142	1·133	1·125	1·117	1·109	1·102	1·095	1·089	1·083	1·077	1·072
16°	1·189	1·178	1·168	1·157	1·148	1·139	1·130	1·122	1·114	1·107	1·100	1·094	1·088	1·082	1·077
17	1·196	1·184	1·174	1·163	1·154	1·145	1·136	1·128	1·120	1·113	1·106	1·100	1·093	1·088	1·083
18	1·202	1·191	1·180	1·170	1·160	1·151	1·142	1·134	1·126	1·119	1·112	1·106	1·100	1·094	1·089
19	1·209	1·198	1·187	1·177	1·167	1·158	1·149	1·141	1·133	1·125	1·119	1·112	1·106	1·100	1·095
20	1·217	1·205	1·194	1·184	1·174	1·165	1·156	1·148	1·140	1·132	1·125	1·119	1·113	1·107	1·102
21°	1·225	1·213	1·202	1·192	1·182	1·173	1·164	1·155	1·147	1·140	1·133	1·126	1·120	1·114	1·109
22	1·233	1·222	1·210	1·200	1·190	1·181	1·172	1·163	1·155	1·148	1·141	1·134	1·128	1·122	1·117
23	1·242	1·230	1·219	1·209	1·199	1·189	1·180	1·172	1·164	1·156	1·149	1·142	1·136	1·130	1·125
24	1·252	1·240	1·229	1·218	1·208	1·198	1·189	1·181	1·173	1·165	1·158	1·151	1·145	1·139	1·133
25	1·262	1·250	1·238	1·228	1·217	1·208	1·199	1·190	1·182	1·174	1·167	1·160	1·154	1·148	1·142
26°	1·272	1·260	1·249	1·238	1·228	1·218	1·209	1·200	1·192	1·184	1·177	1·170	1·163	1·157	1·152
27	1·283	1·271	1·260	1·249	1·238	1·229	1·219	1·210	1·202	1·194	1·187	1·180	1·174	1·168	1·162
28	1·295	1·283	1·271	1·260	1·250	1·240	1·230	1·222	1·213	1·205	1·198	1·191	1·184	1·178	1·173
29	1·307	1·295	1·283	1·272	1·262	1·252	1·242	1·233	1·225	1·217	1·209	1·202	1·196	1·189	1·184
30	1·320	1·308	1·296	1·285	1·274	1·264	1·254	1·245	1·237	1·229	1·221	1·214	1·207	1·201	1·195
31°	1·334	1·321	1·309	1·298	1·287	1·277	1·267	1·258	1·250	1·242	1·234	1·227	1·220	1·214	1·208
32	1·348	1·336	1·323	1·312	1·301	1·291	1·281	1·272	1·263	1·255	1·247	1·240	1·233	1·227	1·221
33	1·363	1·350	1·338	1·327	1·316	1·305	1·295	1·286	1·277	1·269	1·261	1·254	1·247	1·240	1·234
34	1·379	1·366	1·354	1·342	1·331	1·320	1·310	1·301	1·292	1·284	1·276	1·268	1·261	1·255	1·249
35	1·396	1·383	1·370	1·358	1·347	1·336	1·326	1·317	1·308	1·299	1·291	1·284	1·277	1·270	1·264
36°	1·413	1·400	1·387	1·375	1·364	1·353	1·343	1·333	1·324	1·315	1·307	1·300	1·293	1·286	1·280
37	1·432	1·418	1·405	1·393	1·382	1·371	1·360	1·350	1·341	1·332	1·324	1·317	1·309	1·303	1·296
38	1·451	1·437	1·424	1·412	1·400	1·389	1·379	1·369	1·359	1·350	1·342	1·334	1·327	1·320	1·314
39	1·471	1·457	1·444	1·432	1·420	1·409	1·398	1·388	1·378	1·369	1·361	1·353	1·346	1·339	1·332
40	1·493	1·478	1·465	1·452	1·440	1·429	1·418	1·408	1·398	1·389	1·381	1·373	1·365	1·358	1·351
41°	1·515	1·501	1·487	1·474	1·462	1·450	1·439	1·429	1·419	1·410	1·401	1·393	1·386	1·378	1·372
42	1·539	1·524	1·510	1·497	1·485	1·473	1·462	1·451	1·441	1·432	1·423	1·415	1·407	1·400	1·393
43	1·563	1·549	1·535	1·521	1·509	1·497	1·485	1·475	1·465	1·455	1·446	1·438	1·430	1·422	1·416
44	1·589	1·574	1·560	1·547	1·534	1·522	1·510	1·499	1·489	1·479	1·470	1·462	1·454	1·446	1·439
45	1·617	1·602	1·587	1·573	1·560	1·548	1·536	1·525	1·515	1·505	1·496	1·487	1·479	1·471	1·464
46°	1·646	1·630	1·616	1·602	1·588	1·576	1·564	1·553	1·542	1·532	1·523	1·514	1·505	1·498	1·490
47	1·676	1·661	1·646	1·631	1·618	1·605	1·593	1·581	1·571	1·560	1·551	1·542	1·533	1·525	1·518
48	1·709	1·693	1·677	1·663	1·649	1·636	1·624	1·612	1·601	1·590	1·581	1·571	1·563	1·555	1·547
49	1·743	1·726	1·711	1·696	1·682	1·669	1·656	1·644	1·633	1·622	1·612	1·603	1·594	1·586	1·578
50	1·779	1·762	1·746	1·731	1·717	1·703	1·690	1·678	1·666	1·656	1·645	1·636	1·627	1·618	1·611
51°	1·817	1·800	1·783	1·768	1·753	1·739	1·726	1·714	1·702	1·691	1·681	1·671	1·662	1·653	1·645
52	1·857	1·840	1·823	1·807	1·792	1·778	1·765	1·752	1·740	1·729	1·718	1·708	1·698	1·690	1·682
53	1·900	1·882	1·865	1·849	1·833	1·819	1·805	1·792	1·780	1·768	1·757	1·747	1·738	1·729	1·720
54	1·945	1·927	1·909	1·893	1·877	1·862	1·848	1·835	1·822	1·810	1·799	1·789	1·779	1·770	1·761
55	1·993	1·975	1·957	1·940	1·924	1·908	1·894	1·880	1·867	1·855	1·844	1·833	1·823	1·814	1·805
56°	2·045	2·025	2·007	1·990	1·973	1·958	1·943	1·929	1·916	1·903	1·891	1·880	1·870	1·860	1·851
57	2·099	2·079	2·061	2·043	2·026	2·010	1·995	1·980	1·967	1·954	1·942	1·931	1·920	1·910	1·901
58	2·158	2·137	2·118	2·100	2·082	2·066	2·050	2·035	2·021	2·008	1·996	1·984	1·973	1·963	1·954
59	2·220	2·199	2·179	2·160	2·142	2·125	2·109	2·094	2·080	2·066	2·053	2·042	2·030	2·020	2·010
60	2·287	2·265	2·245	2·225	2·207	2·189	2·173	2·157	2·142	2·128	2·115	2·103	2·091	2·081	2·071

To convert into Time, multiply by 4. Thus 2′·287 × 4 = 9s·148.
This applies also to the quantities in Table C.

TABLE D.

Shewing the error produced in the Longitude by an error of 1′ in the Altitude.

Lat.	TRUE AZIMUTH. 76°	77°	78°	79°	80°	81°	82°	83°	84°	85°	86°	87°	88°	89°	90°
0	1·031	1·026	1·022	1·019	1·015	1·012	1·010	1·008	1·006	1·004	1·002	1·001	1·001	1·000	1·000
1	1·031	1·026	1·022	1·019	1·016	1·013	1·010	1·008	1·006	1·004	1·003	1·002	1·001	1·000	1·000
2	1·031	1·027	1·023	1·019	1·016	1·013	1·010	1·008	1·006	1·004	1·003	1·002	1·001	1·001	1·001
3	1·032	1·028	1·024	1·020	1·017	1·014	1·011	1·009	1·007	1·005	1·004	1·003	1·002	1·002	1·001
4	1·033	1·029	1·025	1·021	1·018	1·015	1·012	1·010	1·008	1·006	1·005	1·004	1·003	1·003	1·002
5	1·035	1·030	1·026	1·023	1·019	1·016	1·014	1·011	1·009	1·008	1·006	1·005	1·004	1·004	1·004
6	1·036	1·032	1·028	1·024	1·021	1·018	1·015	1·013	1·011	1·009	1·008	1·007	1·006	1·006	1·006
7	1·038	1·034	1·030	1·026	1·023	1·020	1·017	1·015	1·013	1·011	1·010	1·009	1·008	1·008	1·008
8	1·041	1·036	1·032	1·029	1·025	1·022	1·020	1·017	1·015	1·014	1·012	1·011	1·010	1·010	1·010
9	1·043	1·039	1·035	1·031	1·028	1·025	1·022	1·020	1·018	1·016	1·015	1·014	1·013	1·013	1·012
10	1·047	1·042	1·038	1·034	1·031	1·028	1·025	1·023	1·021	1·019	1·018	1·017	1·016	1·016	1·015
11	1·050	1·046	1·041	1·038	1·034	1·031	1·029	1·026	1·024	1·023	1·021	1·020	1·019	1·019	1·019
12	1·054	1·049	1·045	1·041	1·038	1·035	1·032	1·030	1·028	1·026	1·025	1·024	1·023	1·022	1·022
13	1·058	1·053	1·049	1·046	1·042	1·039	1·036	1·034	1·032	1·030	1·029	1·028	1·027	1·026	1·026
14	1·062	1·058	1·054	1·050	1·047	1·043	1·041	1·038	1·036	1·035	1·033	1·032	1·031	1·031	1·031
15	1·067	1·063	1·058	1·055	1·051	1·048	1·045	1·043	1·041	1·039	1·038	1·037	1·036	1·035	1·035
16	1·072	1·068	1·064	1·060	1·056	1·053	1·051	1·048	1·046	1·044	1·043	1·042	1·041	1·040	1·040
17	1·078	1·073	1·069	1·065	1·062	1·059	1·056	1·054	1·051	1·050	1·048	1·047	1·046	1·046	1·046
18	1·084	1·079	1·075	1·071	1·068	1·065	1·062	1·059	1·057	1·055	1·054	1·053	1·052	1·052	1·051
19	1·090	1·085	1·081	1·077	1·074	1·071	1·068	1·066	1·063	1·062	1·060	1·059	1·058	1·058	1·058
20	1·097	1·092	1·088	1·084	1·081	1·077	1·075	1·072	1·070	1·068	1·067	1·066	1·065	1·064	1·064
21	1·104	1·099	1·095	1·091	1·088	1·084	1·082	1·079	1·077	1·075	1·074	1·073	1·072	1·071	1·071
22	1·112	1·107	1·103	1·099	1·095	1·092	1·089	1·087	1·084	1·083	1·081	1·080	1·079	1·079	1·079
23	1·120	1·115	1·111	1·107	1·103	1·100	1·097	1·095	1·092	1·091	1·089	1·088	1·087	1·087	1·086
24	1·128	1·123	1·119	1·115	1·112	1·108	1·105	1·103	1·101	1·099	1·097	1·096	1·095	1·095	1·095
25	1·137	1·132	1·128	1·124	1·120	1·117	1·114	1·112	1·109	1·108	1·106	1·105	1·104	1·104	1·103
26	1·147	1·142	1·137	1·133	1·130	1·126	1·124	1·121	1·119	1·117	1·115	1·114	1·113	1·113	1·113
27	1·157	1·152	1·147	1·143	1·140	1·136	1·133	1·131	1·129	1·127	1·125	1·124	1·123	1·122	1·122
28	1·167	1·162	1·158	1·154	1·150	1·147	1·144	1·141	1·139	1·137	1·135	1·134	1·133	1·133	1·133
29	1·178	1·173	1·169	1·165	1·161	1·158	1·155	1·152	1·150	1·148	1·146	1·145	1·144	1·144	1·143
30	1·190	1·185	1·180	1·176	1·173	1·169	1·166	1·163	1·161	1·159	1·158	1·156	1·155	1·155	1·155
31	1·202	1·197	1·193	1·188	1·185	1·181	1·178	1·175	1·173	1·171	1·169	1·168	1·167	1·167	1·167
32	1·215	1·210	1·206	1·201	1·197	1·194	1·191	1·188	1·186	1·184	1·182	1·181	1·180	1·179	1·179
33	1·229	1·224	1·219	1·215	1·211	1·207	1·204	1·201	1·199	1·197	1·195	1·194	1·193	1·193	1·192
34	1·243	1·238	1·233	1·229	1·225	1·221	1·218	1·215	1·213	1·211	1·209	1·208	1·207	1·206	1·206
35	1·258	1·253	1·248	1·244	1·240	1·236	1·233	1·230	1·227	1·225	1·224	1·222	1·222	1·221	1·221
36	1·274	1·269	1·264	1·259	1·255	1·251	1·248	1·245	1·243	1·241	1·239	1·238	1·237	1·236	1·236
37	1·290	1·285	1·280	1·276	1·271	1·268	1·264	1·262	1·259	1·257	1·255	1·254	1·253	1·252	1·252
38	1·308	1·302	1·297	1·293	1·289	1·285	1·281	1·279	1·276	1·274	1·272	1·271	1·270	1·269	1·269
39	1·326	1·321	1·316	1·311	1·307	1·303	1·299	1·296	1·294	1·292	1·290	1·289	1·288	1·287	1·287
40	1·345	1·340	1·335	1·330	1·326	1·322	1·318	1·315	1·313	1·310	1·309	1·307	1·306	1·306	1·305
41	1·366	1·360	1·355	1·350	1·345	1·342	1·338	1·335	1·332	1·330	1·328	1·327	1·326	1·325	1·325
42	1·387	1·381	1·376	1·371	1·366	1·362	1·359	1·356	1·353	1·351	1·349	1·347	1·346	1·346	1·346
43	1·409	1·403	1·398	1·393	1·388	1·384	1·381	1·378	1·375	1·373	1·371	1·369	1·368	1·368	1·367
44	1·433	1·427	1·421	1·416	1·412	1·407	1·404	1·401	1·398	1·395	1·394	1·392	1·391	1·390	1·390
45	1·458	1·451	1·446	1·441	1·436	1·432	1·428	1·425	1·422	1·420	1·418	1·416	1·415	1·414	1·414
46	1·484	1·477	1·472	1·467	1·462	1·458	1·454	1·450	1·447	1·445	1·443	1·442	1·440	1·440	1·440
47	1·511	1·505	1·499	1·494	1·489	1·485	1·481	1·477	1·474	1·472	1·470	1·468	1·467	1·467	1·466
48	1·540	1·534	1·528	1·522	1·518	1·513	1·509	1·506	1·503	1·500	1·498	1·497	1·495	1·495	1·494
49	1·571	1·564	1·558	1·553	1·548	1·543	1·539	1·536	1·533	1·530	1·528	1·526	1·525	1·524	1·524
50	1·603	1·597	1·590	1·585	1·580	1·575	1·571	1·567	1·564	1·562	1·560	1·558	1·557	1·556	1·556
51	1·638	1·631	1·625	1·619	1·614	1·609	1·605	1·601	1·598	1·595	1·593	1·591	1·590	1·589	1·589
52	1·674	1·667	1·661	1·655	1·649	1·645	1·640	1·636	1·633	1·630	1·628	1·626	1·625	1·625	1·624
53	1·713	1·705	1·699	1·693	1·687	1·682	1·678	1·674	1·671	1·668	1·666	1·664	1·663	1·662	1·662
54	1·753	1·746	1·739	1·733	1·728	1·723	1·718	1·714	1·711	1·708	1·705	1·704	1·702	1·702	1·701
55	1·797	1·789	1·782	1·776	1·770	1·765	1·761	1·757	1·753	1·750	1·748	1·746	1·745	1·744	1·743
56	1·843	1·835	1·828	1·822	1·816	1·811	1·806	1·802	1·798	1·795	1·793	1·791	1·789	1·789	1·788
57	1·892	1·884	1·877	1·870	1·864	1·859	1·854	1·850	1·846	1·843	1·841	1·839	1·837	1·836	1·836
58	1·945	1·937	1·929	1·922	1·916	1·911	1·906	1·901	1·897	1·894	1·892	1·890	1·888	1·887	1·887
59	2·001	1·993	1·985	1·978	1·972	1·966	1·961	1·956	1·952	1·949	1·946	1·944	1·943	1·942	1·942
60	2·061	2·053	2·045	2·037	2·031	2·025	2·020	2·015	2·011	2·008	2·005	2·003	2·001	2·000	2·000

To convert into Time, multiply by 4. Thus, 2′061 × 4 = 8^{s}·244.
This applies also to the quantities in Table C.

The preceding Table is printed on coloured paper to distinguish it from Table C, which is partly printed in Red.

CHAPTER XV.

TO FIND THE ERROR AND RATE OF A CHRONOMETER.

Equal Altitudes not recommended.

Hitherto the recommendation has been to effect this by "Equal Altitudes" of the sun, A.M. and P.M., taken with the Artificial Horizon. This method, however, though short and simple, so far as the figures go, is open to many objections. The operation cannot be completed at one time, since several hours must elapse before the second half of the observations can be made. During this tedious interval, the conditions which existed in the morning may be considerably changed. For example, the refraction may have increased or diminished, owing to a shift of wind or fall of rain; the observer's "Personal Equation," as it is termed, may have varied; and the divisions of the sextant may have altered, through the effect of heat or cold in expanding or contracting the metal.

Disadvantages enumerated.

Raper says—"The method, even under the most favourable circumstances, can rarely be considered as affording extreme precision"; and all the things just mentioned tend to vitiate the accuracy of the result in a greater or less degree. Furthermore, the setting in of cloudy weather may cause the morning's work to be so much labour thrown away, by rendering impossible the corresponding P.M. altitudes; and, in any case, there is the inconvenience (sometimes very great) of a double journey to and from the ship, and a repetition of chronometer comparing. It is true the A.M. sights could be used as "Absolutes," but every one accustomed to this sort of work knows the suspicion which attaches to observations taken only on one side of the meridian.

Personal Equation.

The term "Personal Equation," though very familiar to astronomers, may be new to many sailors, so it is as well to explain it. It has been found that most men, however expert, have a fixed habit of "making contact" either too soon or too late, depending for amount upon their nervous organization in general, and their bodily state at the time, whether of rest or fatigue, sickness or health. It is even found that an easy or constrained position of the individual at the moment of observation may exercise considerable effect on the result. Thus the excitable man, fearing to miss the event, is apt to forestall it; while the man of phlegmatic disposition is more likely to be too late. In fact, each individual is found to have a certain definite rate of perception, or what Miss Agnes M. Clerke, in her beautifully-written *System of the Stars*, calls "rate of sense-transmission." **Personal peculiarities**

The human eye, also, in its measurement of distance, varies in different people. One man may consider the sun's limb to be just touching the horizon, whilst another, using the same sextant, will consider it a trifle above it; and a third be impressed with the idea that the sun is too low, and that both the others are wrong. No doubt, to this, as much as to instrumental errors, is to be attributed the difference among officers in the common operation of taking the sun at noon.

These may seem insignificant trifles to some, but the process of chronometer rating is itself a delicate one; and it must be remembered that, in the necessary splitting of seconds, we are dealing with quantities susceptible of the most minute influences.

The principle of finding the error of a Time-keeper by "Equal Altitudes" is, that the earth rotating at a uniform rate, equal altitudes of a fixed body on either side of the meridian will be found at equal intervals from the time of transit of that body over the meridian, and that, therefore, the mean of the times of such equal altitudes will give the time at transit, which for the sun is noon.

How to eliminate Errors of observation.

The better mode—taken all round—is to observe stars east and west of the meridian, within a few minutes of each other—by which *all* systematic errors, whether atmospheric, instrumental, or personal, are practically neutralized in the *mean* result. Moreover, with "Equal Altitudes," it unavoidably happens, when the latitude and declination are of contrary names, that the sun being badly situated, from the slowness of his motion in altitude, cannot be expected to give good results. Now this need never be the case with the stars; a couple on or near the Prime Vertical, east and west, can always be found at some hour of the night, let the latitude be what it may. When selecting stars, choose those that have about the same altitude, and will therefore be equally affected by refraction. To avoid error due to a want of parallelism in the surfaces of the glass roof of the Artificial Horizon, reverse it for opposite stars, *so that the same side may,*

Reversal of Artificial Horizon.

*in every case, be next to you.** If the regular mercurial horizon is not to be had, an extempore one can easily be rigged up with a soup plate, and some oil or treacle. On a *calm* evening this makes a 100 A1 substitute.

In the observation of the altitude of a star with the Artificial Horizon, it is always troublesome to bring down the image of the star reflected from the sextant mirrors to the image reflected from the mercurial horizon, or *vice versâ;* and sometimes, when two bright stars stand near each other, there is danger of employing the reflected image of one of them for that of the other. A very simple method of avoiding this danger, and of facilitating the observation, was suggested by the late Karl Knorre, of Dorpat, when Professor of Practical Astronomy at the School of Navigation in Nikolajew.

Professor Knorre's method of observing Stars.

"It can be proved geometrically, that whenever the direct and reflected images of any star are made to coincide in the field of view of the sextant, the index glass will be inclined at a constant angle to the horizon. (This angle is equal to the inclination of the sight-line of the telescope to the horizon glass.) If, therefore, we attach a small spirit level to the index arm, so as to make with the index glass an angle equal to this constant angle, the bubble of this level will play, whenever the two images of the same star are in coincidence, in the middle of the field of view.

"With a sextant thus furnished, we begin by directing the sight-line towards the image in the mercury; we next move the index until the bubble plays, taking care not to lose the image in the mercury. The reflected image from the sextant mirrors will then be found in the field, or will be brought there by a slight vibratory motion of the instrument about the sight-line.

"A sextant is easily fitted up on this principle, the level being made out of a small glass tube of little more than one inch in length. In sextants of the usual construction, the reading lens is attached to a stem that turns round a short pillar fixed at right angles to the index arm; in these cases the level may be attached to the same pillar, rotating stiffly round it to admit of preparatory adjustment, and then fixed once for all in its proper position."

Chronometer rating in Suez Canal.

When made fast for the night in the Suez Canal—now the great highway to the East—the writer has found it very con-

* In taking "absolutes" or independent observations of the sun (not Equal Altitudes), the roof must be reversed when half way through the desired number.

venient to ascertain the errors of his chronometers by the method above advocated. The Admiralty plan gives the exact latitude and longitude of each end of the canal, from which, with a little care and neat-handedness, the geographical position of any other point may be determined. But for the convenience of those who may distrust their own measurements, a few positions are subjoined, from which others can more readily be fixed.

	Latitude.		Longitude.
	° ′ ″		° ′ ″
Port Said high lighthouse - - - - -	31 15 45 N.	-	32 18 45 E.
The 25 mile post at Kantara siding - -	30 50 45 N.	-	32 19 15 E.
Palace at Ismaïlia - - - - - - - -	30 35 30 N.	-	32 16 45 E.
The 52 mile post at northern entrance to Great Bitter Lake - - - -	30 25 45 N.	-	32 21 00 E.
The 74 mile post near Chalouf - - -	30 8 20 N.	-	32 34 24 E.
South Pier Head of Port Ibraham - -	29 56 10 N.	-	32 33 12 E.

The correct latitude and longitude of a place being known, the principle of determining Greenwich Mean Time, whereby to ascertain the error of a chronometer, may be explained in a few words. Every navigator is aware that his daily sights give him the *Apparent Time at Ship*, and that by applying the Equation of Time he gets *Mean Time at Ship*. Of course the same thing applies to the determination of *Mean Time on Shore*. Now, if he knows (from the chart or otherwise) the exact longitude of the spot where he took his sights, and turns it into time, he has merely to add or subtract it (according as it is west or east) to or from this *Mean Time at Place*, to obtain at once the correct *Mean Time at Greenwich*. This, compared with the corresponding time by chronometer, gives its error, fast or slow, as the case may be. Since the above was written Panama Canal has become an accomplished fact.

Principle of getting the correct G.M.T. by observation on shore.

Here it is necessary to be clear on one point. When this comparison is made of the Chronometer time with the Greenwich time, it is to be distinctly understood that the "*Original error*" and "*Accumulated rate*" are to be entirely disregarded, and not allowed to enter into this part of the calculation. The actual difference then existing between the Chronometer and Greenwich times is to be taken as a *new* original error—entirely independent of the first one, which is no longer to be employed. This is particularly dwelt upon, from the fact that many men compare the *corrected* Chronometer time with the Greenwich Mean Time, and in after work apply *both* errors, and even carry on the old rate, when they have all the materials for getting a new and more correct one.

"Original Error" and "Accumulated Rate."

Rating Chronometers by sights at sea.

Sometimes, also, the error of the longitude by chronometer is found by the ordinary sights taken off an island or headland passed in the course of the voyage; and this error—say 12′—is improperly applied as a constant correction to all longitudes subsequently determined, instead of working out the error in *time* of the chronometer, and so arriving at the *sea rate* for future use.

With reference to this custom of taking sights at sea when the ship's position is fixed by cross-bearings of well-known land, it is certainly very useful as a rough check *if the vessel has been away from port for a considerable time:* for example, it might be done with advantage by a homeward-bound East Indiaman when passing Cape Agulhas, or by an outward-bounder when passing St. Paul's Rocks, near the equator.*

But if the chronometers have been *recently* rated on shore the errors inseparable from such observations at sea would probably exceed the errors in the rate given by the maker. Thus many smart vessels pass Madeira when only a week out, and this might be considered a good opportunity for testing the chronometer rates: but though sights so taken might be useful in detecting gross errors, if such were suspected, *they could not be relied upon* under ordinary circumstances to give the time with the needful precision for *rating* purposes. More useful results might indeed be obtained if the vessel were stopped, so as to combine P.M. with A.M. observations; or in the event of her passing in the afternoon a second point of land equally well determined with the first. In either case the mean of the two sets would perhaps give a fair approximation to the truth.

Interval necessary for Rating.

To find, on shore, the *rate* of a chronometer, its error on Mean Time must be known on two days, separated by an interval of not less than six, or more than ten days. Then the difference between the two errors, divided by the number of days in the interval, will give its daily rate for the time being. Where the interval is a long one, say a month or six weeks, during which the temperature has varied considerably, the *mean* daily rate is that which will be obtained, and may differ considerably from the performance of the chronometer at time of last observation. This goes to prove the necessity of adopting *Temperature rates*, as recommended by Mr. Hartnup.

* Both these are very accurately determined positions:—

St. Paul's Rocks...............Lat. 0° 55′ 30″ N. ...Long. 29° 23′ 00″ W.
Cape Agulhas Lighthouse...Lat. 34° 49′ 46″ S.. ...Long. 20° 0′ 41″ E.

To watch the performance of a chronometer on shore, it is not by any means necessary for the observer to know his longitude, as the error of the chronometer on *Local* Mean Time is all that is wanted. It may be done also by simply noting the time of the successive disappearances of any star (not a *planet*) behind a smoothly-planed straight-edged board, nailed in a truly vertical position against some firm support. The observer's eye must be always at the same point, such as a small hole in a tin plate, also nailed to an immovable support, at a distance of say 30 or 40 feet from the board, and to the north or south of it, according to the particular star selected.

Rating by Transit of Star.

This is a very excellent practical method, and one capable of much precision. To carry it out, proceed as follows:—On any given evening, note the time by chronometer of the star's disappearance, which—from a star being a mere luminous point, without sensible diameter—is so sudden as to be at first quite startling; and after an interval, say of six days, do the same again. On account of a Sidereal day being shorter than a Mean Solar day, the star will disappear sooner each evening by 3m. 55·9s.; therefore multiply this quantity by the number of days between the observations, and subtract the result from the time shewn by chronometer at first observation.

Example of Rating by Star Transit

If the chronometer is keeping exactly Mean Time, the first and second times will now agree; if they do not, the difference is the loss or gain of the chronometer. If the second time is greater than the first, it is evident the chronometer is gaining, and the difference divided by the number of days gives its daily rate.

EXAMPLE.

At Philadelphia, on October 16th, 1880, the star Fomalhaut was observed to disappear at 14h. 2m. 18·5s. by chronometer.

On Oct. 22nd the disappearance was timed at 13h. 38m. 34·0s. Required the daily rate of chronometer.

			H. M. S.		M. S.
Oct. 16.	Star disappeared at	.	14 2 18·5		3 55·9
			— 23 35·4		× 6
			13 38 43·1		23 35·4
Oct. 22.	Star disappeared at	.	13 38 34·1		
	Loss in 6 days	. . 6)	9·0(	1·5s. daily rate losing.	
			6		
			30		
			30		

The same purpose may be achieved by equal altitudes of a star on the same side of the meridian taken on different nights, and requires neither Epitome nor Almanac.

Select a star on or near the Prime Vertical, and, to avoid errors due to variable refraction, let its altitude be considerable—say 40° or 45°. Note the time and Altitude, and after an interval of five or six days, again note the time at the same altitude. To find the *rate* proceed as in the last example.

Of course an artificial horizon must be employed, and care taken to set the sextant exactly to the same altitude, allowing for any difference in the Index-error.

To find the Error of a Chronometer by Stars East and West.

We will now give an example of finding the *Error* of a chronometer on Greenwich Mean Time by observations of stars east and west, taken with an Artificial Horizon on shore. The observations are *bonâ fide*, and selected at random from among quite a large number, taken on the same occasion. They were expressly made to determine the meridian distance between Valparaiso and Tongoy, the latter being a port of which the author was then engaged in making a trigonometrical survey.*

Sunday, August 15th, 1875.—The following sights were taken at Valparaiso, in front of the Port Captain's office, in latitude 33° 2′ 6″ S., and longitude 4h. 46m. 32·1s. W.; Fort San Antonio being taken at 71° 38′ 0″ west of Greenwich. Index error +1′ 30″ Chronometer, from previous observations at Arica, assumed to be 51·6s. slow of Greenwich Mean Time.†

* The plan of Tongoy, with others from the same source was afterwards published by the Hydrographic Office of the Admiralty.

† In November of 1883, whilst engaged making a chain of telegraphic meridian-distances, Lieut.-Commander (now Admiral) C. H. Davis and party definitely settled the position of what had been the site of Fort San Antonio, as under:—

	°	′	″
Latitude	33	1	52 S.
Longitude	71	38	42·3 W.

The fort, however, had been demolished, and the spot referred to covered by the buildings of the Custom House. The cupola of the Exchange, at the landing place, according to the same authority, is in

	°	′	″
Latitude	33	2	7·3 S.
Longitude	71	38	36·3 W.

* Spica, bearing about N. 88° W. true.

	H. M. S.		° ′ ″
Time by Chronometer	13 3 32·0	Observed angle ✱ Spica	46 51 10
Assumed error	+ 51·6	Index error	+ 1 30
			2)46 52 40
G.M.T., August 15th	13 4 23·6	✱'s apparent altitude	23 26 20
		Refraction (Table 31 of *Raper*) . .	— 2 10
		✱'s true altitude	23 24 10

	° ′ ″		
	90		
✱'s Declination .	10 30 41 S.		
Polar distance .	79 29 19	Cosecant	0·007350
Latitude . . .	33 2 8	Secant .	0·076584
Altitude . . .	23 24 10		
	135 55 37		
Half sum . . .	67 57 49	Cosine .	9·574257
Remainder . .	44 33 39	Sine . .	9·846130

	H. M. S.
Sidereal time at G.M. noon, Aug. 15th	9 33 56·83
Acceleration for 13h.	+ 2 8·13
„ „ 4m.	+ ·66
„ „ 24s.	+ ·06
Right Ascension of mean ☉ . .	9 36 5·68

	H. M. S.	
9·504321 = Stars hour Angle .	4 35 18·00 W.	
✱'s Right Ascension	13 18 37·61	
Right Ascension of the meridian .	17 53 55·61	or Sidereal time
Right Ascension of the mean ☉ . .	9 36 5·68	at place.
Mean time at place	8 17 49·93 P.M.	
Longitude of observation spot . .	4 46 32·10 W.	
Mean time at Greenwich	13 4 22·03	
Time by Chronometer	13 3 32·00	
	s.	
Chronometer slow of G.M. time . .	50·03	

For an explanation of the term Right Ascension of the Mean ☉ refer back to page 400.

Fomalhaut, the other star of the pair, is worked out below in a manner exactly similar to the foregoing: its hour angle, however, being East has to be *subtracted* instead of added.

* Fomalhaut, bearing about S. 72° E. true.

	H. M. S.		° ′ ″
Time by chronometer	13 20 00·0	Observed angle ✱ Fomalhaut . . .	62 53 20
Assumed error	+ 51·6	Index error	+ 1 30
G.M.T., August 15th	13 20 51·6		2)62 54 50
		✱'s apparent altitude	31 27 25
		Refraction (Table 31 of *Raper*) . .	— 1 32
		✱'s true altitude	31 25 53

	° ′ ″		
	90		
✱'s Declination	30 16 46 S.		
Polar distance .	59 43 14	cosecant	0·063699
Latitude . . .	33 2 8	Secant .	0·076584
Altitude . . .	31 25 53		
	124 11 15		
Half sum . . .	62 5 37	Cosine .	9·670272
Remainder . . .	30 39 44	Sine . .	9·707550

	H. M. S.
Sidereal time at G.M. noon, Aug. 15th	9 33 56·83
Acceleration for 13h.	+ 2 8·13
„ „ 20m.	+ 3·28
„ „ 52s.	+ ·14
Right Ascension of mean ☉ . . .	9 36 8·38

	H. M. S.	
9·518105 = ✱'s hour Angle .	4 40 20·50 E.	
✱'s Right Ascension	22 50 48·00	
Right Ascension of the meridian .	18 10 27·50	or Sidereal time
Right Ascension of the mean ☉ . .	9 36 8·38	at place
Mean time at place	8 34 19·12 P.M.	
Longitude of observation spot . .	4 46 32·10 W.	
Mean time at Greenwich	13 20 51·22	
Time by chronometer	13 20 00·00	
	s.	
Chronometer slow of G.M. time . .	51·22	

Both stars—Spica especially—were favourably situated in azimuth, and their very close agreement (the difference amounting only to 1·19s.) proves conclusively that not only were the altitudes and times accurately observed, but that all the conditions must have been normal.

The mean of the two results gives 50·62s. as the error of the chronometer on August 15th.

At Arica, on August 7th, the same chronometer was 46·40s. slow of G.M.T., shewing that in the interval of 8 days it had lost 4·22s., equal to a daily rate of 0·53s.

"Original Error."

It will be noticed that in comparing the Chronometer time of observation with the Greenwich Mean time of observation, the *original error* 51·6s. was not taken into account. At the commencement of the calculation, however, it was used to get the *Greenwich date* as closely as possible, whereby to reduce correctly any of the data requiring it, such as the Sidereal Time at Greenwich mean noon, &c.

It is evident that if the chronometer error were neglected, when at all large, many of the elements used in the calculation would be inaccurate. This is less the case, however, with the stars (which may be regarded as fixed) than it would be with the sun or planets. In the case of the moon, which alters her Declination and Right Ascension very rapidly, the error would be excessive. For this and other reasons the moon is never used in this connection.

In the Suez Canal, under certain conditions, sights may very well be taken on board ship, and when this can be done it is of course much more convenient and pleasant than squatting down on a sandhill. Acting on the suggestion of Captain Lee, then of the Transport "Capella," the writer tried this several times during the war in Egypt, and got results in every way satisfactory.

A ship observatory.

As a stand for the Artificial Horizon, a small table was placed close over on the starboard side of the saloon deck, and the observer was comfortably seated in a chair with a Quartermaster standing by with a bull's eye lamp, kept dark till required for reading off. The 2nd officer sat *behind* the observer (back to back), with the chronometer and lamp facing him on a third chair. In this way three sets (of three in a set) were taken of the Eastern star, and after shifting the gear over to the port side, a similar number were taken of the western star.

To make this plan possible, it is necessary to wait till all hands have turned in, as the most cautious footfall on deck is at once revealed by the star's image dancing in the quicksilver: even the donkey engine for feeding the boilers must be stopped for the time-being. If there is any wind, the Artificial Horizon and observer may be sheltered by a weather-cloth, rigged up for the purpose; and, with the awning overhead, you are as comfortable as in a regular observatory—*always barring the Mosquitoes.*

About 11 o'clock P.M. Wednesday, September 20th, 1882, the following sights were taken on board Her Majesty's Transport *British Prince*, then moored for the night to the west bank of the Suez Canal, midway between mile posts 36·6 and 36·7. This position when laid off on the Admiralty plan gave the latitude 30° 39′ 30″ N., and the longitude 32° 20′ 0″ E. Index error −40″. Chronometer, from previous observations taken on the mole at Alexandria, assumed to be 2m. 14s. slow of G.M.T. **Position of observation spot.**

∗ Saturn, bearing N. 87¼° E. true.

	H.	M.	S.
Time by chronometer	9	10	14·5
Assumed error	+	2	14·0
G.M.T., September 20th	9	12	28·5

	°	′	″
Observed angle ∗ Saturn	61	2	30
Index Error		−	40
	2)61	1	50
Saturn's apparent altitude	30	30	55
Refraction (Table 31 of *Raper*)		− 1	37
Saturn's true altitude	30	29	18

	°	′	″		
Polar distance	73	00	20	Cosecant	0·010391
Latitude	30	39	30	Secant	0·065389
Altitude	30	29	18		
	134	9	8		
Half sum	67	4	34	Cosine	9·590516
Remainder	36	35	16	Sine	9·775285
					9·450581

	H.	M.	S.
Sidereal Time at G.M noon, September 20th	11	57	5·86
Acceleration for 9h. 12m. 29s.	+	1	30·76
Right ascension of mean ☉	11	58	36·62

	H.	M.	S.
9·450581 = Saturn's hour angle	4	16	42·8 E.
Saturn's reduced Right Ascension	3	37	7·8
Right Ascension of the meridian	23	20	25·0
Right Ascension of the mean ☉	11	58	36·6
Mean Time at ship	11	21	48·4 P.M
Longitude of ship in time	2	9	20·0 E.
Mean Time at Greenwich	9	12	28·4
Time shewn by chronometer	9	10	14·5

	M.	S.
By ∗ Saturn, chronometer slow of G.M.T.	2	13·9

So much for the eastern star, now we will see what the western one says.

* Altair, bearing S. 81° W. true.

	H.	M.	S.
Time by chronometer	9	29	57 8
Assumed error	+ 2	14	0
G.M.T., Sept. 20th	9	32	11·8

	°	′	″
Observed angle * Altair	62	20	00
Index error		—	40
	2)62	19	20
Altair's apparent altitude . . .	31	9	40
Refraction (Table 31 of *Raper*) . .		— 1	34
Altair's true altitude	31	8	6

	°	′	″		
Polar distance	81	26	9	Cosecant	0·004870
Latitude . . .	30	39	30	Secant .	0·065389
Altitude . . .	31	8	6		
	143	13	45		
Half sum . .	71	36	53	Cosine .	9·498869
Remainder . .	40	28	47	Sine . .	9·812364

	H.	M.	S.
Sidereal Time at G.M. noon, September 20th	11	57	5·86
Acceleration for 9h. 32m. 12s. . . .	+	1	33·97
Right Ascension of mean ☉ . . .	11	58	39·83

	H.	M.	S.
9·381492 = Altair's hour angle . . .	3	55	3·0 W.
Altair's R.A.	19	45	5·0
Right Ascension of the meridian	23	40	8·0
Right Ascension of the mean ☉	11	58	39·8
Mean Time at ship	11	41	28·2 P.M.
Longitude of ship in time	2	9	20·0 E.
Mean Time at Greenwich	9	32	8·2
Time shewn by chronometer	9	29	57·8
		M.	S.
By * Altair, chronometer slow of G.M.T. .		2	10·4

The mean of the two results gives 2m. 12·2s. as the error of the chronometer on September 20th. Seven days afterwards, when at Malta, the Greenwich Mean Time, carried on from these observations, was found to differ only a second and a half from the Time Ball.

Where delicate observations are required, the planets Jupiter and Venus are out of the running, from the fact that they are so very much bigger and brighter than the mere speck which a star presents; the latter, therefore, is to be preferred, but in this as in many other matters, external circumstances control our wishes, and it is often a case of do-with-what-you-can-get without being too fastidious: or in other words, be thankful for the bread even if it is not buttered. On this account it is deemed advisable to give an example showing the working of a planet which it will be noticed is precisely the same as the working of a fixed star, if we except the necessity for reducing the Declination and Right Ascension to the Greenwich Mean Time of Observation. In the case of Saturn the reduction is very small.

When several altitudes of each star have been taken, which is the proper thing to do, they should be worked out *separately*, and not in groups, or sets, of three or five. By so doing, palpable mistakes in reading off the sextant, or taking the time, &c., declare themselves at the finish, and the particular observations which contain them, if incapable of adjustment, can be rejected *in toto*. It is true this very materially increases the labour of calculation, but the man who strives to be accurate will not grudge it. Having thrown out the bad, if any, the mean results of the remainder will then be reliable.

A number of observations should be worked out separately.

Since the telegraphic determination of the longitude of the principal places on the globe, Time signals have been established at a great number of ports for the benefit of shipping.

Time signals are also, of recent years, sent by radio-telegraphy from some of the world's wireless stations. The United States Naval Radio Stations, for example, have sent out time signals in this way since August, 1913; and the French station at Eiffel Tower has a still longer record of usefulness under this head. When the dogs of war are howling round a nation's coasts such time-signals by radio-telegraphy are naturally omitted. The experience of the *Cestrian* may be quoted as an example of the utility of this method. Within a week she received radio time signals on not fewer than five days. One in 41° 55′ N., 69° 48′ W., a second in 32° 38′ N., 73° 30′ W., a third in 25° 32′ N., 79° 42′ W., a fourth in 25° 26′ N., 84° 17′ W., and a fifth in 28° 12′ N., 88° 34′ W. The sending stations were respectively Boston, Key West on three occasions, and Pensacola.

For chronometer purposes, lists of such stations must be regarded as open to alterations. Neither geographical position, nor type of time signal, of a shore station is invariable. Change either in the time of *making* the signal, or in the geographical position of the station, *is easily ascertained on inquiry*.

When the signal is made by gun fire, the time of the *flash* must be noted; but if from any cause this cannot be seen, it will be necessary to fall back upon the *report*. In which case, allow for the velocity of sound in air at the rate of 1,090 feet per second, when the thermometer registers 32° Fahr. As the temperature increases, the velocity increases at the rate of 1·15 of a foot for each degree, decreasing in the same proportion for temperatures lower than 32°. Thus at 55° Fahr. we have the velocity = 1,116 feet per second, and at 80° Fahr. it is 1,145 feet per second. Taking into account so many facilities, the error in the Greenwich Mean Time of any sailing ship should never exceed 20s., and in steamers should certainly not amount to half this quantity.

Flash and Report of Time-Gun.

Velocity of Sound in Air.

Time signal arrangements vary much at different places, as

Time signal arrangements vary much at different places, and it is of importance that those desirous of profiting by them should make themselves fully acquainted, by enquiry from the proper authorities, with the exact nature of the local regulations concerning them. At many ports, the error (if any) in making the signal is published in the next day's papers; here, for example, is a specimen cut out of the New York "World."

WESTERN UNION TIME-BALL.

NEW YORK, February 22.—The time-ball on the Broadway tower of the Western Union Telegraph Company's building, which is dropped daily (Sundays excepted) at mean noon of the 75th meridian by the standard time of the United States Naval Observatory at Washington, was dropped to-day exactly at noon, equivalent to 5h. 0m. 0·0s. Greenwich Mean Time.

Always inquire

The Harbour Master's office is generally the best place to institute inquiry.

In the bye-ports where time-signals do not happen to exist, the pains-taking Navigator can fall back upon his faithful allies, the sextant and the artificial horizon. He is sure to have the first, and the last is quickly fixed up with a soup-plate and some clear molasses.

It has been demonstrated that a star East, meaned with a star West, will give an exact result. The time necessary to observe the pair, say a set of five for each, varies from 20 minutes to half-an-hour, according to proficiency. A beginner would probably take 45 minutes; but once he makes a start at this work, the time will diminish and his interest will increase.

Stars *versus* sun.

In the tropics it will be found more pleasant to observe stars in the cool of the evening than to perspire in the sun by day. In the latter event, not only does the observer get his nose peeled (which is annoying), but his eyes suffer from the glare (which is worse).

Even in *certain* of the ports abroad where Time-Signals *do* exist, it is wise to keep a check upon them. If the signal be observed daily, a fairly good chronometer will soon tell whether it be reliable or otherwise, for even admitting any trifling variation in the daily rate of the chronometer, it will always be less than the error of observing the signal.

If things look doubtful, you can pit yourself against the observatory. Take sights with sextant and artificial horizon, and repeat same after an interval of a week. Observe signal daily, and of course compare chronometers daily. Of course, also, you are provided with the Admiralty large scale plan of the port, and from this it is easy to get the *exact* Latitude and Longitude of your "Observation Spot." You have then all the materials to saddle the right horse. Should the signal prove unreliable, kindly acquaint "Wrinkles," for the benefit of navigators in general, through the Publishers.

Checking Time-signal.

The leading countries of the world are now bestowing much consideration on the establishment of Time-Signals which shall be convenient not only for mariners, but for folks in general. It has ever been a maxim that "Punctuality is the soul of business," and its truth is becoming more apparent every day—our big steamship passages to wit.

Not the least of the improvements is the unification and standardizing of National Time now in progress almost everywhere. England keeps Greenwich time throughout; Ireland kept Dublin time, but now Greenwich; France keeps Paris time; Cape Colony keeps the time of the meridian of 30° E.; Germany, Austria, Italy, and Denmark have adopted "Mid-European Time," namely, that of the meridian of 15° E. In Denmark Time-Signals are made at Greenwich Mean Noon in the Telegraph Offices of over a dozen seaports, and admission is free to seamen; so that by simply carrying a chronometer on shore at these places the correct time can be had gratis. This is probably copied from the American system; for example, on the Pacific Coast of the United States the Mare Island Observatory furnishes Standard Time to each of the following ports:—

Standardizing National Time

San Diego	California.	Seattle	Washington.
Santa Barbara	California.	Tacoma	Washington.
Santa Cruz	California.	Olympia	Washington.
San Francisco	California.	Portland, Oregon.	

At each of these ports a clock in the office of the W. U. Telegraph Co. is synchronized by hand and ear, while the signal is coming in on a sounder alongside, to 120th Meridian Time, these clocks, in turn, correcting hourly other clocks in local circuit with them. At the present time there are about a thousand clocks so controlled, and the system is being rapidly extended.

Synchronized clocks.

Navigators can obtain at the W. U. Telegraph Office, in each of the above mentioned ports, the correct time at noon of the 120th meridian (= 8h. 0m. 0s. G.M.T.) by direct signal from Mare Island; or the correct time at any other hour within the limit of running of the clocks in those offices.

Also, in the Branch Hydrographic Office, Merchants' Exchange, San Francisco, a clock is set each day directly by signal; and at *that* office chronometer comparisons may be obtained *at any time.*

Owing to vastness of territory, the United States authorities have adopted five Standard Times, namely, that of the meridians of 60° (Inter-colonial), 75° (Eastern), 90° (Central), 105° (Mountain), and 120° (Pacific); but only three of these affect their sea-board.

Australia—another large continent—has followed suit as follows:—

West Australia	... 120° E.
South Australia	... 142° 30′ E.
Victoria...	... 150° E.
Queensland	... 150° E.
New South Wales	... 150° E.
Tasmania	... 150° E.
New Zealand	... 172° 30′ E.

Natal and Japan have also come into line, having respectively adopted 30° E. and 135° E.; and Russia uses time of Pulkowa meridian, 2h. 1m. East of Greenwich. Eventually other countries will be sure to drop into a similar system; in China, more especially, there is plenty of room to carry it out.

In Egypt the official time kept is that of mean noon at the Great Pyramid, or 2h. 4m. 20·5s. fast of Greenwich Meantime. Railways, telegraphs, also Cairo and the Nile, keep local mean-time of the Abbasizeh Observatory, or 2h. 5m. 8·9s. fast of Greenwich. Turkey uses time two hours fast of Greenwich, for the purposes of navigation; but, among the people, the day of 24 hours begins at sunset. India's time is 5½ hours fast of Greenwich; Hong-Kong and the East Coast of China adopt the meridian of 120° E.; British Columbia uses 120° W. A list of time signals, brought down to date, is published by the Admiralty in the Light Lists.

It is well to remember that occasionally nations, and colonies, make alterations in standard time, which have to be guarded against by the new arrival. A plain question to a responsible official soon rectifies any tendency to error under this head.

The date, or calendar line, passes through points in 60° S. 180° E., 51° 30′ S. 180° E., 45° 30′ S. 172° 30′ W., 15° 30′ S. 172° 30′ W., 5° S. 180° W., 48° N. 180° W., 52° 30′ N. 170° E., 65° N. 169° W., the centre of Bering Strait, and 70° N. 180° W. East of the line drawn through these points the date in the Calendar is American, west of the line it is Asiatic.

CHAPTER XVA

NEW METEOROLOGICAL MEASURES FOR OLD!

Officers of the world's navies, of peace and of war, have of recent years come into comparatively close touch with radio-telegraphy, submarine signals, search lights, electrically driven sounders, and interesting items of like nature, to an extent that would appal an old-time sailing-ship man of the single-topsail era could he revisit our planet from the shades. Innovation is seldom regarded from a favourable point of view by a large majority of those who are directly responsible for the safety of life and of property at sea. Many a navigator has deemed, still deems, and will hereafter deem, an aneroid good enough for every purpose in connection with either storm-sailing or with conditions of weather that are more favourable. Even at the commencement of the twentieth century, when matters nautical are well to the fore, the aneroid, in active service on board merchant ships, irrespective of flag, is preferred before a mercury barometer for practical purposes. It is sometimes strenuously urged that an aneroid not infrequently evinces a nasty knack of changing its error without warning, or of maintaining an error of exceptional magnitude. Well, any officer who is continuously using an aneroid in practical navigation, as though it were absolutely free from tendency to err, is open to deserved censure. No one is infallible, not even the youngest of us, to quote a Cambridge Don; and a ship-master who has a reputation to lose, or one to gain, will often take the necessary steps to ensure a careful comparison, not only of the readings of his working aneroid, but also of those of his mercury barometer, with synchronous readings of shore stations and of other similar instruments on board his own ship. There are but few ships without several aneroids on board! All these are not likely to go wrong at the same instant of time. Some of the pointers with respect to comparisons of chronometers may be conveniently extended, with a slight change of words, to comparisons of aneroids.

It is against chances that all the aneroids or all the chronometers on board a given ship, shall elect to choose the same instant for a dangerous departure from the normal. In order to bring the indications of an aneroid into line with synchronous observations at a near shore station it is necessary to remember that the shore station data, as a general rule, will all have been corrected and reduced, in the accepted way, for height above mean sea-level, temperature, and gravity. Hence until the synchronous ship's observations have been similarly treated, they will not be comparable with the corrected and reduced readings of a shore station. Once the error of an aneroid is known, the method of procedure is as easy as falling off a log—to use a proverbial expression of Jack. One thing seems certain. Despite an admitted tendency to radical revolution in that life on the ocean wave so bepraised in song and in story by men who have carefully avoided getting wet with salt water, the English language, like Tennyson's brook of the poem, seems destined to "go on for ever," and to hold its own—if not more—against all comers.

Whether the prevailing British standards of measurement will survive the flight of time, after the manner of Horace's verse, and maintain their impregnable position, is perhaps open to doubt. What is good enough for English-speaking races, under these heads, does not necessarily appeal so powerfully to dwellers on the Continent of Europe and elsewhere as the English language does. Nearly one hundred and twenty years ago when the then much-vaunted metric system was brought to the front in the United Kingdom, there were not wanting writers of considerable mathematical calibre who alleged that decimal and centesimal divisions were about to supplant sexagesimal methods such as seemed good to our forefathers in their pride of nation. The revolutionists were nothing if not thorough, in their own estimation. With them the day was to consist of forty centesimal hours, each comprising one hundred minutes of one hundred seconds; and the earth's circumference was to contain just four hundred grades, each of which was made up of one hundred minutes of one hundred seconds. Consequently ten, not fifteen, would be used in connection with conversion of time into longitude, or longitude into time. A brand-new centesimal minute of latitude, known to the true believers as a kilometre, was to serve as the centesimal sea-mile. Eighty years later this mislaid metric system came on to the United Kingdom educational market once again; and apparently would not be denied. The so-called metric system enjoyed quite a boisterous boom in some schools, and was boldly backed by the examination of such pupils as had suffered its influence under the auspices of certain public bodies who may, or may not, have been familiar with the subject they professed to admire. This suggested substitution of new measures for old was eloquently and persuasively advocated by sections of schoolmasters, compulsorily tested by the results of promising pupils at public examinations, and severely left alone by every one who preferred to view the situation from a platform that was not only *practical* but also *British*. Inasmuch as in this metric system the mere shifting of a decimal point, to right or to left, was assumed to effect much saving of labour on the part of computers, it seems that success should have been assured to its adoption. Unfortunately, as Burns once sang, the plans of men and mice gang aft agley. The decimal point not infrequently displays quite an uncanny knack of putting in an appearance out of proper position; so that the result, to the Britisher at any rate, is merely an object lesson in misapplied energy. Under the system of grades, minutes, and seconds, owing to the fact that a minute was one-hundredth of a grade, and a second was one-hundredth of a minute, it was possible to write an angle containing 36 grades, 25 minutes, 29·39 seconds, as simply 36·252939 grades. Such simplicity, to many a navigator, is more apparent than actual. English-speaking seafarers—American and British—plumped for the retention of the time-honoured system in which a right angle is divided into ninety equal angles, each of these ninety degrees equals sixty minutes, and each minute equals sixty seconds. Computers of experience, whether sitting in a snug room on dry land, or on board ship under more critical conditions, will soon become competent to work with any scale whatsoever for thermometer and barometer. Seafarers, however, are not solely occupied with this class of theoretical pyrotechnics, and the vast majority, for whom the mental catering has to be carried out in order to succeed, will naturally look askance at a compulsory change that involves a radical revolution in their appreciation of the indication afforded either by a thermometer or by a barometer. Even now the watch below of many a junior officer is not infrequently encroached upon by clerical duties that are carried on to a finish, without fee or hope of substantial reward, for various Public Departments of the several maritime nations. An eminent mathematical authority, formerly of the British Royal Navy, in an impartial summary, not only of the merits but also of the demerits of the once much-proclaimed Metric System, during the course of an article in the *Nautical Magazine* of 1891, employed pregnant periods that are as fertile to-day as they decidedly were then. His words may rightly be extended to cover the nakedness of the methods that are suggested for reading the thermometer and the barometer on board ships of all sorts and conditions. "But unfortunately for the completeness of the system," he wrote, "so beautiful on paper, the world refused to have anything to do with centesimal time, and therefore, sexagesimal being retained, the kilometre is useless for the purposes of navigation, and even the French retain and print on their ordnance maps the *mille* alongside the kilometre." Slightly changing the wording of this statement, to meet a more nautical view, it will probably apply with like truth to the suggested methods of reading and recording barometers and thermometers on board ships engaged in the ocean carrying trade.

Seafarers of the United Kingdom, United States, Canada, Australia, New Zealand, and other countries, where English is the language in use by people of every degree, read barometers in inches and decimals of an inch of mercury, and thermometers in degrees and parts of a degree of that time-honoured Fahrenheit scale in which 32° is the freezing-point of water, and 212° is its boiling-point. At the same time these countless seafarers record the wind velocity in miles an hour, or in feet per second; and also employ an inch scale for measurements of rainfall. All classes of the community, on the Continent of Europe, cling tenaciously to the Centigrade system for the thermometer; millimetres for the barometer; metres per second, or kilometres per hour, for the wind velocity; and millimetres for the measurement of rainfall. English is the official language of many a league of dry land, near and far; it is in use exclusively on a large majority of the world's shipping; and, needless perhaps to say, English-speaking races, outside the comparatively confined domains of highly scientific coteries, adhere to the old-fashioned way to which they and their forefathers have been accustomed. Seafarers, more especially, prefer the inch and decimals of an inch of mercury, or its equivalent by aneroid indication, for barometric purposes; and the degree and decimals of a degree, of the Fahrenheit scale, for thermometric records. It is even doubtful whether teachers and schoolmasters of English-speaking peoples are eager to swap horses, as it were, while crossing the stream, any more readily than are those whose lives are spent on blue water remote from pedagogues and parsons. "In Meteorology," to quote from an eminent authority of to-day, "the metric measures are not more systematic than the British; for both are arbitrary." Yet but a few years ago, at least over the United Kingdom, that despised metric system was lauded to the skies, by men of light and leading, as certain to supplant the time-tried measures of those countries where the English language is *facile princeps.* Such crisp statements as *Veni, Vidi, Vici* may have served their purpose among the ancient Romans; but they are utterly out of place in the metric system's swan-song.

Consequent on the more recent introduction of units based upon a curious Centimetre-Gramme-Second (C.G.S.) system, for measurements in those scientific subjects to which Modern Meteorology is closely allied, it has been proposed, in all seriousness, to adopt that system for barometer, thermometer, and other items not nearly so intimately connected with the everyday life of a seafarer. It would appear that, but for the success of aviation, and the relative conquest of the upper regions by daring practical navigators of airships, the favourite barometric inches and Fahrenheit degrees would have served every purpose outside arcana of science. Advances in aerial navigation, and in radio-telegraphy, have, it is said, brought with them a need for a flexible system of measurements that shall be of international application. Here, perhaps, comes in the apposite nature of the old proverb that you may lead a horse to the water, but it is for the led one to decide whether he will drink thereof. Similarly the mariner—and it is with him only that *Wrinkles* is concerned—may be brought alongside the newest of new systems of measurement, as regards atmospheric pressure and the temperatures of air and of sea, but the last word lies with the mariner in active service as to their adoption. Some of the most earnest of the promoters of the proposed system seem to have misgivings under that head. "If one wishes to find out persons of intelligence to whom metric units are unfamiliar and repulsive, we have literally to think of special classes of engineers and meteorologists." The term "meteorologist" is of rather an elastic nature; and we may perhaps quite rightly include English-speaking navigators among an overwhelming majority who are outside the pale of collegiate training. Curiously enough that eminent writer seemed to anticipate at least a suspicion of difficulty; inasmuch as, when referring to the marked attachment of English-speaking peoples for the old type of units of measurement, it was admitted that "when the sailors are counted in, there is a very large body of meteorological observers who are in favour of the customary inch-Fahrenheit units." It is said that to publish meteorological data in English, without having translated the figures given in the text, is practically to restrict the publication to a very limited circle of readers. *A fortiori* it may rightly be urged that to publish meteorological data in the suggested units of apparently somewhat *German* origin is to deprive myriads of an intellectual treat who are only familiar with that almost universal language—English to wit.

Aerology with its phenomenally low barometric pressures of from two to six inches of mercury, coupled with an alleged dread of complications introduced by the many minus signs in thermometric records of the upper air, has led to an apparent demand for change. Temperatures of $-20°$, and even as low as $-60°$, are equally awkward to deal with by a novice, whether in the time-honoured Fahrenheit scale so beloved by the English-speaking seafarer, or in the Centigrade scale preferred before all others by the nations of the Continent of Europe. Atmospheric pressures of from two inches to six inches of mercury, high aloft, instead of the more usual pressures of from twenty-seven inches to thirty-one inches recorded on the earth's surface, introduce an altogether new conception, so it is affirmed, to the observer. "A scale of temperatures including positive and negative signs is dangerous for the observer, troublesome for the computer, awkward for the printer, misleading for the reader, and is altogether unsuitable." A more sweeping condemnation of the prevailing barometer and thermometer units of English-speaking races of to-day is perhaps difficult to find. Nevertheless, these British units, in so far as seafarers are concerned, may easily survive the flight of time. Assuming that the proposed substitution of new and unfamiliar measures, for old and familiar measures of repute, shall shortly become an accomplished fact, then, not only the Fahrenheit scale, but also the Centigrade scale, will have to be thrown overboard to lighten the ship of science. Inches and millimetres equally cumber the vessel's decks, and therefore shall share a like fate. Barometers and thermometers will require regraduation; if not simultaneously, then in quick succession. There will be a golden harvest for instrument-makers, and an aftermath of trouble for observers and others most intimately concerned, should such an innovation succeed in winning a way beyond high-water mark around the coasts. One incontrovertible argument against the suggested substitution of 400° for 360°, as the measure of a complete angular revolution, was based upon the consequent necessity for recalculating books of mathematical tables with which navigators and others are familiar by reason of continuous use. Similar, and equally weighty, objections hold in connection with radical changes in the methods of recording temperature and atmospheric pressure if attempts should be made to enforce them in the conduct of ships remote from examination rooms and cramshops. Charts setting forth the results of these data, so that he who runs may read, in the form of isobars and isotherms, are published all the world over at great expense, which is borne by the national exchequer. Such aids to safe navigation would demand, provided that the proposed changes were carried out to the bitter end, a continual reference to books of conversion tables, so as to ensure that the last state of the navigator shall not be worse than his first. Whether the readings of barometers and of thermometers are displayed in the old measures consecrated by many years' use, or be in the brand-new style that has yet to form a plank in the platform of the practical navigator, we must freely admit that either system is merely conventional. When we say that a barometer reading is 28 inches, or 30 inches, for example, we almost automatically connect the particular reading with a particular kind of weather that varies according to the ship's geographical position on the waste of waters, or rather with the average barometer reading corresponding to the weather. And this, quite regardless of the fact that the reading in course of consideration has not been corrected for height of the barometer cistern above sea-level, for temperature, or for gravity. It is too frequently forgotten, or ignored, that the average values derived from ships' observations on the open sea are not the results of continuous series. No two nations will deduce average isobars and isotherms, from the data in their possession, that do not agree to differ. Mathematical analysis may determine which is the greater evil—discontinuity of series, or kind of barometer used.

The Centimetre-Gramme-Second system of units, which may, or more likely may not, become of universal application ashore and afloat, is based on the metric system, in which the multiplication and the division of the unit by 10, 100, and 1000, are indicated by the prefixes deka, hecto, kilo, and deci, centi, milli, respectively. A centimetre is one-hundredth part of a metre, whence the designation metric system, and is equal very nearly to ·394 of an inch. A gramme is the metric unit of mass. It approximates nearly to the mass of a cubic centimetre of water at the freezing point, and is equal to 15·4 grains. There are 86,400 seconds in a mean solar day. Under this Centimetre-Gramme-Second system the 0° Centigrade, and its corresponding 32° Fahrenheit, disappear as such. The thermometers for this system are graduated in degrees Centigrade from a zero that is 273° below the freezing-point of fresh water, which is no longer either 0° C. or 32° F., but 273*a*, 273° A., or 273° Absolute to write it in full. It will thus be seen that continental methods of measuring temperature threaten the supremacy of the familiar scales preferred before all others by English-speaking races. One point in favour of the suggested change is deserving of close consideration. Temperature records will cease to be burdened with a minus sign, thus perhaps lessening the chances of mistakes both by recorders and by computers. This item is, however, of trifling importance, either to seafarers using beaten tracks, or to dwellers in the United Kingdom. Should the Centimetre-Gramme-Second system ever win a way seaward the navigator will be met with the fact that it entails more work upon him. On reading his new-fangled thermometer, showing so-called "absolute degrees," he will find the number 293 where 68 served his every purpose on the Fahrenheit scale. Hence he will have more figures to write, and therefore be cursed with an increased tendency to error in reading and recording. Nevertheless, he altogether avoids the use of the minus sign in so far as temperature records are concerned. This last, however, is an unimportant consideration for navigators between the latitude parallels of 60° N. and 60° S. The most modern forms of barometer that are coming into being under the ægis of the British Meteorological Office presided over by Sir Napier Shaw, F.R.S., are graduated in such a way that they read millibars directly when they are in latitude 45° and at a temperature of 285 A. (54° F.). For other latitudes and other temperatures corrections are necessary as with the inch barometer. An anomaly of the latter instrument is that its temperature has to be 25° F. in latitude 45°, or 0° F. on the equator, or 57·7° F. at either pole, if we desire to get it in such a state as to give, without any correction, the pressure of the air at the surface of the mercury in the cistern. Such excursions into high science do not trouble practical navigation! Needless to say, perhaps, a millibar is not even distantly related to our old friend the capstan bar. A millibar is the Centimetre-Gramme-Second unit chosen for atmospheric pressure measurements; and one mercury inch is equivalent to 33·8632 millibars. Thermometers attached to mercury barometers will be graduated in absolute degrees, as above mentioned; and doubtless thermometers for recording the temperature of the air will follow suit for scientific purposes, on dry land where the English language is easily first. There is more than a suspicion of doubt whether the English-speaking seafarer will take kindly to the Centimetre-Gramme-Second for meteorological records remote from the coasts. Throughout a long series of years the lunar formed a prominent plank in examinations for the "extra-master" certificate. That was a flagrant example of fostering a candidate's cramming capacity; and, after much searching of heart, occasioned in part by *Wrinkles*, the lunar has ceased to form a part of Board of Trade examinations. The measurement by sextant of the lunar distance, which alone pertained to practical navigation and was the crux of the matter, was not required of a candidate; so that it was easy for him to be figure-perfect in an examination room so as to arrive at a correct rule-of-thumb result, working with the data placed before him, yet be absolutely unable to determine the distance between the moon and other heavenly body by the aid of the sextant. The mathematical treatment of the problem was also utterly disregarded. Consequent on this peculiar method of examination, candidates for the "extra" certificate were taught—not that they might know, but that they might pass. Once in possession of the coveted certificate, the lucky seafarer seldom, if ever, troubled his practical brain with this rule-of-thumb twister, which was based on the old-fashioned practical lunar method that went out with the wind-jammer. It is certainly open to argument whether the recently introduced Centimetre-Gramme-Second system will not share the ignominious fate of the once much-advertised and little-used lunar. The causes of death will doubtless be certified as almost identical. A well-known Hydrographer, the late Captain Sir E. J. Evans, R.N., at a Science Conference just forty years ago, took occasion to point out that too often there is not sufficient care exercised in discriminating between what is required for philosophers and what for seamen. His weighty words hold good to-day! Whatever tends to make information for seamen less simple, less clear, more bulky, or more costly, he said, is to be deprecated.

Seafarers who care to delve deeper into this subject, which seems likely to form a part of Board of Trade examinations on much the same lines as those that obtained for the theoretical lunar, should obtain a copy of a work entitled *Practical Physics*, by Glazebrook and Shaw, and assimilate the mental food provided in the attractive chapter that deals with units of measurement. Many of the readers of *Wrinkles*, far from academic advantages, may experience a difficulty in obtaining a copy of *Practical Physics*. Hence it seems desirable to give a short résumé of the views there set forth with critical clearness. The method of measuring a quantity, say those eminent physicists, is resolvable into two parts: (1) the selection of a suitable unit, and (2) the determination of the number of times that this unit is contained in the quantity to be measured. The selection of a suitable unit "is, and must be, entirely arbitrary—that is, at the discretion of the particular observer who is making the measurement." Hence it would appear from this that the thousands of seafarers familiar only with mercury inches of barometer and Fahrenheit degrees of thermometer should be continued as arbiters of their fate under this head. In order, however, that an observer's results may be readily understood, and open to verification by others destitute of his apparatus, the unit selected must be capable of reproduction under other circumstances of place and time, and of comparison with the units used by other observers. Hence a tendency to the adoption of common standards of length, of mass, and of time. Units, such as the yard, the pound weight, and the second, are arbitrary. Other units of like nature are the degree as a unit of angular measurement, the thermometric degree as a unit of the measurement of temperature, and similar items. "The difficulty, however, of obtaining an arbitrary standard which is sufficiently permanent to be reproducible makes this arbitrary method not always applicable; . . . the arbitrary choice of a unit for a particular quantity is directed by a principle of selection which makes it depend upon the units already selected for the measurement of other quantities. We thus get systems of units, such that when a certain number of fundamental units are selected, the choice of the rest follows from fixed principles. Such a system is called an 'absolute' system of units, and the units themselves are often called 'absolute,' although the term does not strictly apply to the individual units." Three units, known as fundamental units, may be chosen arbitrarily. No one of the three units is derivable from the other two. In the absolute system now being brought to the notice of mariners compulsorily, those most intimately concerned not having been consulted, the fundamental units are the centimetre, gramme, and second. Hence it is known as the Centimetre-Gramme-Second system, or, more concisely, the C.G.S. system. The units on this absolute scale are related to each other in the following way, having due regard to the fact that the millibar has been adopted as the working unit. Ten millibars = 1 centibar; ten centibars = 1 decibar; and ten decibars = 1 bar. Millibars and centibars are the values most likely to interfere with the seafarer's watch below. The relation between the millibar of the new-fashioned mercury barometer and the mercury inch of the old-fashioned instrument, is given below in tabular form; as also a comparison between the readings of a thermometer on the Fahrenheit principle and one on the Absolute principle. The reading in Centigrade corresponding to any reading in Absolute is directly obtainable by subtracting 273 from the latter. It must be remembered that a reading of a ship's mercury barometer has to be corrected for index error, temperature, height above sea, and gravity, before the reading is comparable with a reading in millibars or centibars. An aneroid reading requires only corrections for index error and height above sea-level.

Equivalents in Mercury Inches at 32° and Latitude 45° of Millibars:—

Millibars.	0	1	2	3	4	5	6	7	8	9
	Mercury Inches.									
920	27·17	27·20	27·23	27·26	27·29	27·32	27·35	27·38	27·41	27·44
930	27·46	27·49	27·52	27·55	27·58	27·61	27·64	27·67	27·70	27·73
940	27·76	27·79	27·82	27·85	27·88	27·91	27·94	27·97	28·00	28·03
950	28·05	28·08	28·11	28·14	28·17	28·20	28·23	28·26	28·29	28·32
960	28·35	28·38	28·41	28·44	28·47	28·50	28·53	28·56	28·59	28·62
970	28·65	28·67	28·70	28·73	28·76	28·79	28·82	28·85	28·88	28·91
980	28·94	28·97	29·00	29·03	29·06	29·09	29·12	29·15	29·18	29·21
990	29·24	29·26	29·29	29·32	29·35	29·38	29·41	29·44	29·47	29·50
1000	29·53	29·56	29·59	29·62	29·65	29·68	29·71	29·74	29·77	29·80
1010	29·83	29·86	29·89	29·92	29·94	29·97	30·00	30·03	30·06	30·09
1020	30·12	30·15	30·18	30·21	30·24	30·27	30·30	30·33	30·36	30·39
1030	30·42	30·45	30·48	30·51	30·53	30·56	30·59	30·62	30·65	30·68
1040	30·71	30·74	30·77	30·80	30·83	30·86	30·89	30·92	30·95	30·98
1050	31·01	31·04	31·07	31·10	31·13	31·16	31·18	31·21	31·24	31·27

Differences for tenths of a millibar:—

mb.	·1	·2	·3	·4	·5	·6	·7	·8	·9
in.	0·003	0·006	0·009	0·012	0·015	0·018	0·021	0·024	0·027

TABLE FOR CONVERSION OF FAHRENHEIT DEGREES (F.°) TO ABSOLUTE DEGREES (A.°).

F.°	A.°	F.°	A.°	F.°	A.°	F.°	A.°	F.°	A.°
20	266·3	40	277·4	60	288·6	80	299·7	100	310·8
21	66·9	41	78·0	61	89·1	81	300·2	101	11·3
22	67·4	42	78·6	62	89·7	82	0·8	102	11·9
23	68·0	43	79·1	63	90·2	83	1·3	103	12·4
24	68·6	44	79·7	64	90·8	84	1·9	104	13·0
25	69·1	45	80·2	65	91·3	85	2·4	105	13·6
26	69·7	46	80·8	66	91·9	86	3·0	106	14·1
27	70·2	47	81·3	67	92·4	87	3·6	107	14·7
28	70·8	48	81·9	68	93·0	88	4·1	108	15·2
29	271·3	49	282·4	69	293·6	89	304·7	109	315·8
30	271·9	50	283·0	70	294·1	90	305·2	110	316·3
31	72·4	51	83·6	71	94·7	91	5·8	111	16·9
32	73·0	52	84·1	72	95·2	92	6·3	112	17·4
33	73·6	53	84·7	73	95·8	93	6·9	113	18·0
34	74·1	54	85·2	74	96·3	94	7·4	114	18·6
35	74·7	55	85·8	75	96·9	95	8·0	115	19·1
36	75·2	56	86·3	76	97·4	96	8·6	116	19·7
37	75·8	57	86·9	77	98·0	97	9·1	117	20·2
38	76·3	58	87·4	78	98·6	98	9·7	118	20·8
39	276·9	59	288·0	79	299·1	99	310·2	119	321·3

CHAPTER XVI.

COMPASS ADJUSTMENT.

Reference books.

An exhaustive enquiry into this most important subject must involve a whole book on it alone, whilst in these pages we can but afford it a chapter. For more complete information, the student cannot do better than read up the books in the *Nautical Library*, taking them in the order 4 and 5 of first batch, and 16 of second batch. Even here, however, before treating of the *practical* part of the work, it is *absolutely necessary* to explain some of the principal features of the *theory*, since it is certain that anyone who attempts Compass Adjustment by mere "rule of thumb," without clearly comprehending the laws upon which it is based, cannot rightly hope to perform it satisfactorily. A short preliminary canter round the outskirts of the subject will therefore do no harm.

Magnetism and electricity.

The remarkable force inherent in the globe, known as Terrestrial Magnetism, which gives a determinate direction to a freely suspended magnetic needle, and is of inestimable value to man, has long been the subject of observation and study. The nature and mode of operation of magnetism and the allied phenomena of electricity continue to be the subject of speculation, for until a very few years ago no explanation of them had been proposed such as that which referred heat and light to the vibrations of an elastic medium; but scientific men are not idle, and the refined investigations constantly being prosecuted add almost daily to the rapidly accumulating store of human knowledge.

"Magnetic Field."

It has been shewn that when a disturbance is set up in one place, which leads to the formation of a "magnetic field," the change from the original condition of the ether to the complex condition known as the "magnetic field," is marked by a magnetic or electro-magnetic propagation of the disturbance. The theoretical velocity of this propagation is the same as the velocity of light (186,320 miles per sec.). In a linear current the direction of the current is the direction of propagation, the disturbance being propagated in the ether and not in the conductor. Without a linear conductor to guide the propagation, the disturbance is propagated equally in all directions, and Clerk-Maxwell advanced the proposition that light is a phenomenon of this order, an electro-magnetic phenomenon involving vortical stresses, rather than the mere vibration of an elastic ether. This was strikingly confirmed by the researches of Hertz in 1888, and since then the science of light has been made a part of the general science of electro-magnetism.

Light and magnetism.

Our knowledge of the phenomena of terrestrial magnetism, whilst advancing with cognate branches, still remains in the empirical stage, It is, however, held that the earth's magnetism is distributed through its mass, and that the magnetic force either wholly or mainly resides in the interior, and cannot be attributed to external influences, though it may be affected by them. As to the ultimate origin of the earth's magnetism as a whole, it is not possible in the present state of the science to formulate any satisfactory hypothesis. But this is soaring into the higher flights, and we must return gently to something more prosaic.

The Earth a magnet.

The Earth, therefore, may be regarded as a huge magnet, whose magnetic poles (two in number) are entirely distinct from its poles of rotation. That in the northern hemisphere, at time of its discovery, by Sir J. C. Ross, R.N., on 1st June, 1831, was situated in Boothia Felix, to the N.N.W. of Hudson Bay, in British North America. Amundsen relocated it in 1904 near King William's Land. The other, discovered by Shackleton, is in 72° 25′ S. 154° E., on ice-topped Victoria Land.

Position of Magnetic Poles.

Unlike the *Geographical Poles,* which are represented by a mere point, the *Magnetic Poles* include a considerable area of the earth's surface, amounting perhaps to 50 square miles.

Their position is found to vary according to some yet unknown law.

The North Magnetic Pole lies in approximately 70° N. 97° W., and the South Magnetic Pole is in 72° S. 154° E. The magnetic poles of the earth do not therefore lie symmetrically at the extremities of a diameter.

As the magnetism of the north end of a needle is of the opposite kind to that of the north pole of the earth, physicists are not agreed as to which should be called *north* magnetism; if the earth be taken as the standard—which is a logical thing to do—it follows that the North-seeking pole of the needle must be considered as a *true* South pole, and *vice versâ*. Meanwhile it is found convenient to distinguish them by colour, calling the north-seeking end of the needle red, and the North Magnetic Pole of the earth blue. The distinction may be easily remembered by supposing the needle coloured, and R occurring in noRth and in Red; U in soUth and in blUe.

At the north magnetic pole, the red or north end, and at the south magnetic pole, the blue or south end, of a freely-suspended needle, points vertically downwards; or in other words, at both these places the "dip" is 90°.

First law in Magnetism.

Here may be stated the first general law in magnetism—namely, that *opposite* poles *attract*, and *similar* poles *repel* each other. From which it follows, that if we decide to colour red that end of the needle which points to the north, the magnetism of that part of the earth must be considered as blue.

Treating the earth's magnetic intensity as a whole, that is to say, without resolving it into its varying horizontal or vertical elements, it appears to be unevenly distributed; nor do the points of maximum *intensity* coincide with either of the magnetic poles.

"Total force."

In the northern hemisphere there are two foci of maximum force of unequal intensity, the more powerful existing in about 52° N. and 92° W., near the great American lakes; the weaker in 70° N. and 120° E., in Siberia. Though the available data are not so complete, there is strong reason to believe that in the southern hemisphere also are two foci of maximum force of nearly equal power, and not far removed from one another; one in Lat. 70° S., Long. 145° E., and its counterpart in 50° S. and 130° E.

Measurement of magnetic force. Adopting English standards of weight and length, the unit by which magnetic force is measured has been assumed to be that which would impart to a weight of one grain a velocity of one foot in one second of time; and by this scale the magnetic force, where least, is found to be 6·1. The northern maxima just mentioned are 14·2 and 13·3 respectively, and the southern are 15·5 and 15·0 respectively.*

The *Variation* of the needle from the *True Meridian* is the resultant of these unequal forces operating upon it; the easterly or westerly tendency of the needle—as the case may be—depending upon the geographical position of the place of observation in its relation to the several foci of force, with a general result of considerable complexity. To simplify matters, however, in what follows, the earth's directive force is assumed to be exclusively centred in the *magnetic poles*, and the needle—when acting in sole obedience to their influence—will be said to point MAGNETIC.

Variation of the Compass. On this assumption, *Variation of the Compass* may be regarded as the angle, measured at the place of the observer, which the magnetic needle, when undisturbed by local attraction or by the ship herself acting as a magnet, makes with the geographical meridian. Variation (or declination, as it is sometimes termed) is due to the fact that the magnetic poles of the earth do not coincide with the poles of rotation. And here a curious anomaly presents itself. Starting from the *North magnetic pole*, one would have to steer due *South by compass* to reach the *true or geographical north pole*, since the needle points not to the *true* but to the *magnetic* pole.

A compass needle, perfectly free from the effects of iron or other magnetic substance, in obedience to the earth's influence, will rest in the plane of the magnetic meridian; or, in other words, its red end will point towards the north magnetic pole. The angular amount, it is pulled to the right or left of this direction by the ship's iron, is termed the deviation of the

* At these foci the "Total force" is between two and three times greater than at the magnetic equator.

Deviation of the Compass.

Compass. The expression "error of the compass" does not always represent the same physical fact. Some confine it solely to the deviation of the compass; others give it a much wider meaning. Variation is due to the earth's influence; deviation is due to the ship's iron. Either difference may be rightly termed error, with the qualifying term variation or deviation; and the algebraical sum of the two may be defined as the total compass error, without fear of confusion. We have, then, variation, deviation, and the sum of the two as total compass error. Thus, if the variation be 20° W., and the deviation 10° W., the total compass error to be applied is 30° W.; and, with variation 20° W., deviation 10° E., the total compass error is 10° W. The deviation is said to be easterly when the north point of the card is pulled to the right or east of north *Magnetic*, and westerly when it is pulled to the left or west of north *Magnetic*. The confusion which sometimes arises as to the effect of deviation on the ship's course may be got over by standing in imagination at the centre of the compass, and conceiving the ship to be sailing thence along any desired point to the margin of the card. Now, since easterly deviation pulls the card to the right, *and the ship follows the card*, it is clear that she also is thrown to the right, and *vice versâ*. "Local Attraction" is the term used to express the disturbance of the compass by magnetic influence existing *outside* of the ship, such as may be found in docks and other confined water spaces.

Effect of Deviation on ship's course.

Local Attraction.

Compass useless near Magnetic Pole.

At the earth's magnetic poles all compass action ceases, since there a freely-suspended needle, pointing straight up and down, *has no horizontal force to give it direction*—hence the very apparent sluggishness of the compass in high latitudes and its *complete uselessness* in the neighbourhood of the magnetic poles. Indeed, were it not for the conical shape of the pivot and cap, which compels the card of a mariner's compass to assume a horizontal position, it would tip over end and jam against the glass cover as the magnetic poles were approached.

Magnetic Equator.

Now, if the earth has *Magnetic Poles*, it has also a *Magnetic Equator*. This magnetic equator is a sinuous curve encircling the earth and crossing the geographical equator in two places nearly diametrically opposite to each other, something after the fashion of the Ecliptic. One crossing is on the eastern side of the Atlantic, about the meridian of 18° West, and the other is in the Pacific, about the longitude of 168° W. Its greatest divergence from the true equator is in Brazil, in latitude 15° S., and longitude 50° W.; its next greatest in the Arabian Sea, at a point in latitude 11° N., somewhere between Socotra and the Laccadives.

Action of freely suspended needle on Magnetic Equator

At all places on the magnetic equator a freely-suspended needle takes a true horizontal position; or, in other words, the dip is 0°. One might imagine that here would be found the strongest lines of *horizontal* or *directive* force; but most careful observations prove that such is not the case—in fact, that of the two, they rather evince a preference for the geographical equator.

To recapitulate:—If a freely-suspended needle be taken to the *north* magnetic pole, its *red* end will point vertically downwards. As the needle is carried south, it will *gradually* approach a horizontal position, which will be exactly attained on the magnetic equator. Proceeding still south, its *blue* end will next begin to dip, and at the *south* magnetic pole will point vertically downwards. These facts have direct reference to the magnetic change which goes on in the iron of a ship, as she alters her *magnetic* latitude in the course of a voyage.

Difference between hard steel and soft iron.

The next most important point to be remembered is the difference between a magnet made of *hard steel* and one made of *soft iron.* That of hard steel will not reverse its poles, no matter at what part of the earth or in what position it may be held. Its magnetic *character* is absolutely permanent, and will so remain even though its red end be directed towards the south, and its blue end towards the north. Hard steel displays no particular haste to receive magnetism, but, once acquired, it does not like to part with it. In this respect it resembles self-taught people; their knowledge—often hard bought—is deeply rooted, and abides with them. Not so, however, with soft iron, which possesses no independent magnetism of its own. In *its* case the magnetism is of a purely transient or fugitive kind, ceasing with the removal of the producing cause, and being just as easily and quickly reproduced with *reversed* poles in the same bar.

Experiments with kitchen poker and boat's compass.

The experiment may be easily tried with an ordinary kitchen poker and a boat's compass. But, first, it will be necessary to explain that a bar of *soft iron,* if held in the earth's "Line of force," will *instantly* become magnetic, though it may not have been so before. Now, what *is* the earth's "Line of force?" It is the position which a *freely-suspended* needle—when undisturbed by iron—would take up if left entirely to itself. In the first

"Line of total Force."

place, it would point towards the magnetic pole; and, in the second place, one end would incline downwards at an angle below the horizon corresponding to the "dip" at the place. The "dip" at London is now (1906) 67°, and slowly diminishing. When, accordingly, the poker is held in this direction, it *at once* becomes magnetic by induction—its *lower* end or point acquiring *red* magnetism in our hemisphere, and its *upper* end or handle acquiring *blue* magnetism. This may readily be tested by placing the compass near it. If held a few inches from the lower or red end, the *south* point of the needle will be attracted by the poker; while, if held near the upper or blue end, the *north* point of the needle will be attracted. This invisible force, exerted by the poker, is termed "*induced magnetism*," or "*magnetism of position*," and only remains so long as the poker is held in that particular manner. To destroy this, it is merely necessary to hold the poker in an east and west direction, or at right angles to the "Line of force," when it will no longer appreciably affect the compass.

"Dip."

Induced Magnetism.

This shews that soft iron has no *fixed* polarity, but that on the contrary, it retains magnetism only precariously, and easily loses it when mechanically disturbed. For example, percussion exercises a marked influence on both the inducing and dispelling of this kind of magnetism. If, therefore, the poker be hit a few taps with a hammer whilst held in the "Line of force," its magnetic power will be intensified; and, again, when the position is altered so as to dissipate the force, it will be found that the tapping hastens that process also.

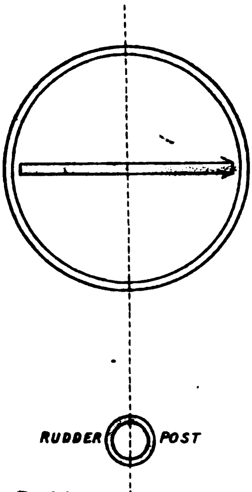
Percussion—its effect.

Let the poker be once more held in the "Line of force"—but this time with the point up and handle down—it will again become magnetic; *but the blue and red magnetism will be found to have changed ends.* The red will have shifted its quarters to the handle, because it is now the lower end, and the blue to the point, because it is now the upper end. Just like water and oil behave in a bottle: the oil will unfailingly be found at the top, no matter which way the bottle may be held.

Change produced in soft iron by geographical change of place.

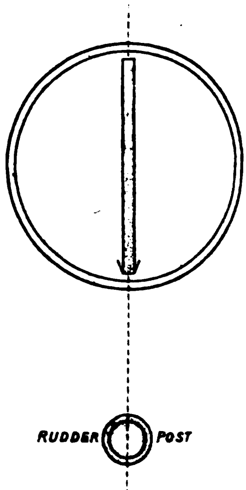
The facility with which soft iron acquires or parts with magnetism may be shewn in another way. Take the kitchen poker, in imagination, to the north magnetic pole, and hold it vertically, point down. The lower end, as before, will acquire "red," and the upper end "blue" magnetism. *Holding it still in the same way,* transport it to the magnetic equator; it will there be entirely free from magnetism of any description. *Still holding it*

Diagram No. 1.



Position of greatest effect.

Diagram No. 2.



Position of no disturbance

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in the same manner, transfer it to the south magnetic pole; it will once more be magnetic, *but*, the lower end will now have "*blue*," and the upper end or handle, "*red*" magnetism. The rapidity of the change will correspond to the time occupied on the journey.

As before stated, *this will not happen with a magnet of hard steel*, whose poles remain unchanged in character, no matter what way it is held, or in what hemisphere it may be placed. Keep this in mind, as it bears directly upon the behaviour of the iron in a ship.

Thus, in north (magnetic) latitude the upper end of all vertical soft iron, such as funnel, masts, stanchions, davits, rudder, stern-post, &c., has *blue* magnetism, and *attracts* the north end of the compass needle. While as the ship sails south, such iron becomes gradually weaker in its effect, and on the magnetic equator—being then at right angles to the "Line of force"—produces none whatever. On the other hand, in south (magnetic) latitude the upper end of this same vertical iron acquires *red* magnetism, *and repels the end of the needle it had previously attracted*, doing so with continuously augmented force as high latitudes are gained. **Effect of vertical iron**

Further, be it remembered that in any given locality the magnetic intensity of a vertical bar of soft iron, such as the rudder post, remains undiminished *no matter what may be the direction of the ship's head*; but its *disturbing* effect on the compass depends upon its position relative to the needle, being greatest when at right angles to the direction of the needle's length, and ceasing when in a line with it (*see Diagrams Nos.* 1 *and* 2). We have now done with *vertical* iron for the present. **Action of vertical iron not dependent on direction of ship's head**

A *horizontal* bar of soft iron at the magnetic pole has no magnetism whatever, since there it is at right angles to the "Line of force." It is, in fact, in the same harmless condition that the vertical bar found itself on the magnetic equator. When taken, however, into low latitudes, it gradually becomes magnetic *if kept pointing towards the magnetic pole*, and has its greatest power in the vicinity of the equator. The *red* magnetism will always be found in the end which points to the north, *no matter which*, turn it about as you may. **Behaviour of horizontal iron.**

As the south magnetic pole is approached, a horizontal bar of soft iron loses force, and at the point of 90° dip, has again ceased to be magnetic. In brief; vertical iron is most magnetic at the poles, and horizontal iron, held in the direction of the meridian, is most magnetic on the equator.

Action of horizontal iron dependent upon the angle it makes with the magnetic meridian.

Another very marked distinction between vertical and horizontal iron must here be noted. The magnetic intensity of the latter depends not only upon its proximity to the equator, *but on the angle it makes with the magnetic meridian.* Thus, when held in a north and south direction (Magnetic), it is at its best; on being turned in azimuth it loses power, and when held exactly east and west (M.) has none at all. Therefore, unlike vertical iron, horizontal iron on board ship has a varying action upon the compass, *depending on the direction of the ship's head as well as on the position of its poles in their relation to the compass needle.*

Horizontal iron produces same deviation in all latitudes.

This is an important distinction; but there is yet another. Horizontal iron produces the same deviation in *all* latitudes; for though its power varies with that of the earth, the ratio between the two is constant; and since the first is the *disturbing* force of the needle, and the other the *directing* force, it follows that the deviation arising from the induced magnetism of horizontal iron is the same at any part of the globe.

By one magnet an indefinite number can be made.

A magnet possesses the peculiar power of producing magnetism in a bar of iron or steel without loss to itself, and so is capable of propagating its own species to any extent. Therefore, when trying experiments with a slice, crowbar, or kitchen poker, it must not be placed *too* close to the compass needle, as the latter, if strong, will of itself induce magnetism in the poker when, from the position in which it may be held at the time, none would otherwise exist. Thus, if a common spike nail be held near one pole of a powerful magnet, the latter will first *induce* magnetism in the nail of a *contrary name to itself,* and then the law which says that *opposite poles attract each other* will come into operation, and the nail in obedience will fly to the magnet.

"Saturation point."

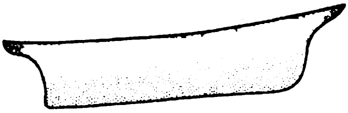
Permanent Magnet.

In the process of making a permanent magnet, which is variously done by "touching" a bar of glass-hard steel with the natural lodestone, with another magnet or by electricity, the one under treatment should be surcharged with the magnetic fluid. It never, however, retains all its original strength; but, after a while, settles down into a certain definite state known as "the saturation point," which, if the steel be of the proper temper, it will maintain for years without appreciable loss, and accordingly gets named a *permanent magnet.*

Neutral point.

Whatever the process of magnetisation may be, it produces two opposite and *equal* forces in the ends of the steel bar, from which it follows that there will be a neutral point about the centre

Diagram No. 3.



SIDE ELEVATION

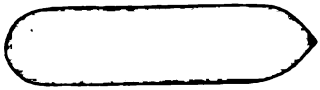


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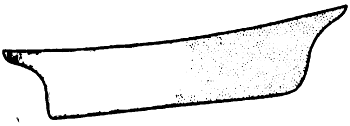
Diagram No. 4.



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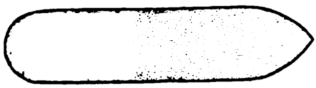

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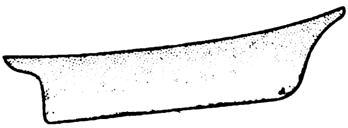
Diagram No. 5.



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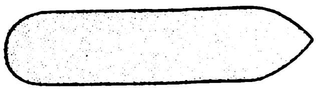

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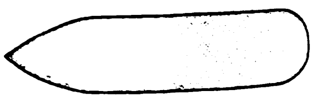
Diagram No. 6.

SIDE ELEVATION



DECK PLAN

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of the bar totally devoid of magnetism of any kind. It is well to know this; since, if it be compulsory to put a compass near vertical iron, it may be possible to raise or lower it to the level of the neutral point, and so render the iron incapable of mischief, so long at least as the ship is upright.*

An iron ship may be correctly looked upon as a large permanent magnet. She became so in the process of construction; for, although the materials of which she is built are not such as by themselves retain magnetism permanently, it is found that, when united in the form of a ship, and subjected to percussion by riveting, &c., they acquire this property in a greater or less degree.

After launching and reversal of the ship's head as it was on the building slip, the magnetism undergoes very rapid diminution; but in no case does it depart *entirely*, and that which is left when the saturation point is reached is accordingly styled *Sub-permanent*. So far there is a great correspondence between the ship, taken as a whole, and the steel magnet. **Sub-permanent Magnetism.**

It is evident that the position of the poles of the ship's Sub-permanent magnetism must depend—first, upon the direction of her head when building; and, secondly, upon the "dip" at the part of the world in which she was built. If, for example, a ship were built at the North Magnetic Pole—direction of her head in this case immaterial—her magnetic constitution would be shewn by diagram No. 3. **Direction of ship's Sub-permanent Magnetic Poles.**

* Magnetism has of late years been used for a very curious purpose, as the following account taken from *Chambers's Journal* for Nov., 1880, will shew:—"It is well known that in working iron, such as welding two pieces together, and even in its manufacture, hollow places or flaws occur, with merely an outside skin over the defective parts, which any test but a destructive one would fail to discover. * * * To test the homogeneity of the metal, Captain Saxby takes a bar of iron and places it on the equatorial line"—(that is to say, in an east and west direction.—*Author.*) "He next passes a compass with a very sensitive needle along in front of the bar—the needle, of course, pointing at a right angle to it. If the bar is perfectly solid through its whole length the needle will remain steady. If, however, there should be a flaw or hollow place in the bar, the needle will be deflected as it passes from the solid to the hollow place, *backwards* towards the solid iron; passing on over the hollow place, the needle will come within the range of the solid iron at the other end of the flaw, and will again be deflected *forward*. If the bar be cut through anywhere between these two points of deflection, a flaw will invariably be found. Many thousands of pieces of iron—some prepared for the purpose of testing this method of trial, others in the ordinary course of business—have been operated upon with the same unvarying result. Captain Saxby has called to his assistance Nature, who never makes mistakes in her operations."

Note:—The writer of this article made a mistake in giving Mr. Saxby the title of Captain. He was Principal Instructor of Naval Engineers in His Majesty's Steam Reserve, and at no time belonged to the Executive branch of the service. By way of light and pleasant reading, sailors would do well to take the Journal just quoted. It contains also the latest scientific "tips" on all subjects.

If built on the Magnetic Equator (head North), diagram No. 4 would represent the state of affairs.

Diagram No. 5 represents a ship built at the South Magnetic Pole, and in this case also the direction of her head would not signify; and *Diagram No.* 6 shews one built at Liverpool—head South.

Endless diagrams might be drawn to shew the effect of the combination of geographical position, with the direction of the ship's head at time of building, on her sub-permanent magnetic character, but the foregoing are sufficient to illustrate what is meant; and the reader, having mastered the principle, can draw for himself any special case he may desire.

We have now shewn that the compasses of a ship are acted upon, first, by her *general* magnetic character, which, so to speak, was born with her, and secondly, by the *induced* magnetism of individual masses of vertical and horizontal iron.

Stability of Sub permanent Magnetism.

The *general* magnetism, after a time, becomes stable in amount, irrespective of geographical position, and the colour of its poles is not subject to change; the *induced* magnetism never becomes so, it is transient, and the colour of its poles depends, in the case of vertical iron, upon the magnetic latitude the ship may be in at the moment; and in the case of horizontal iron, upon the direction of the ship's head.

Varying effect of Sub-permanent Magnetism.

Although the Sub-permanent portion of the ship's magnetism remains constant in all latitudes, its *effect* upon the needle is very different. Near the equator, the horizontal or *directive* force of the needle is at its best, and, accordingly, it is then most fit to resist the disturbing pull of the fixed portion of the ship's magnetism just referred to. But, as we know, the needle *loses* its directive force as polar regions are approached, and, consequently, at such times comes more and more under the domination of the ever vigorous Sub-permanent magnetism. It is consequently necessary to compensate these various effects *by means suitable to each.*

Duty of Steel Magnets.

The *Permanent* portion of the ship's magnetism, which causes *Semicircular or Polar deviation,* is compensated by *steel magnets,* whose magnetism is likewise permanent; and that part due to induction in *vertical* iron, which goes and comes with change of latitude, and likewise causes Semicircular deviation, is compensated by *vertical* bars of ordinary wrought-iron, which similarly become magnetic by terrestrial induction, and are influenced in a corresponding degree by such changes of latitude as both may be exposed to.

Duty of Flinder's bar.

Another part of the ship's magnetism, namely, that arising from the induction of *horizontal* iron, produces *Quadrantal* deviation—which, as before stated, is the same for all latitudes, and is compensated by soft iron, generally in one or other of three forms: namely, *horizontal* cylinders like clock weights, globes like the round shot of Nelson's time, or masses of small close-linked chain. This last is of course enclosed in suitable receptacles. **Quadrantal deviation.**

The Quadrantal error—begotten of induced magnetism in the ship's soft iron—waxes and wanes throughout each quadrant, attaining its maximum in a portion of each quadrant.

The horizontal iron producing Quadrantal deviation may be either athwartships, fore and aft, or oblique; the name of the deviation (+ or −) depends also upon whether the iron producing it is continuous or interrupted in the vicinity of the compass.

It is an axiom in Mechanics that "nothing but force can resist force," and this applies equally well to magnetic force. The correct principle, therefore, to go upon in adjusting compasses appears to be that "Like cures like," when applied on the opposite side to the disturbing influence.

The many diverse causes shewn to operate on the compass at one and the same time, combine in producing a certain sum total of effect, but as these forces do not always act in harmony either as regards direction or amount, it is clear that their joint effect cannot be compensated by any single magnet whose power is the same at all times and in all places. Here the knowledge of the *skilled* compass adjuster comes in, as by certain mathematical rules, by no means difficult of attainment, he is able to *analyse* the magnetic character of the ship, apportion to *each kind* of deviation its *proper value*, and apply the *right kind* of remedy. **Necessity for magnetic analysis.**

To distinguish Quadrantal from Semicircular deviation is quite easy, but to separate that part of Semicircular deviation caused by *vertical iron*, from that part which is produced by the ship's *Sub-permanent magnetism*, is a more difficult task by far; yet, in vessels continually changing their magnetic latitude, this is of the highest importance. **Tracing semicircular deviation to its true cause.**

To adjust a compass, it is necessary to put the ship's head on two adjacent cardinal points, such as North and East; also on any one of the four principal inter-cardinal points, such as N.E.

The Deviation (semicircular) existing when the ship's head is either North or South, is caused by the attraction of the port or starboard side of the ship, according as the attracting pole of her **Ship's head North or South—cause of Deviation.**

magnetism lies to one side or the other, and is compensated by steel magnets placed athwartships. The compass being placed in the amidship fore-and-aft-line of the vessel, and the iron on each side of it being *in general* equally and symmetrically distributed, there is no occasion to compensate the induced magnetism of vertical iron, as that on the port side counteracts that on the starboard side.

In a ship built with head either due North or South, the poles of her Sub-permanent magnetism would exist in the bow and stern, rendering 'thwartship magnets unnecessary, as there would be no deviation on either of these two points; that is, supposing the iron on each side of the compass to be the same in amount and position.* The only effect would be to *increase* the directive force of the needle when the ship's head was on the *opposite* point to that on which she had been built, and to *diminish* it when on the *same* point.

Ship's head East or West—cause of Deviation.

When the ship's head is either due East or West, the Deviation (semicircular) is caused by the attraction of the bow or stern of the vessel, according as the attracting pole of her Sub-permanent magnetism lies forward or aft, *and according to whether the greatest effect of vertical iron is found before or abaft the compass.* The compensation in this case is effected *partly* by *steel* magnets placed fore and aft, *and partly by a vertical pillar of wrought iron.* This vertical pillar is termed a "Flinder's bar," after a Captain in the Royal Navy who was the first to propose it.

In a ship built with head either due East or West, the poles of her *Sub-permanent* magnetism would lie to starboard and port, *rendering fore-and-aft steel magnets unnecessary,* as there would be no Deviation *from this cause* with the ship's head on either of these points, and the rule as to the directive force of the needle would be the same as before.

Knowledge conveyed by being acquainted with direction of Ship's head on building sling.

It is seldom or never that a ship is built with her head *exactly* on one of the cardinal points, so that both fore-and-aft and athwartship magnets are almost invariably required; and when the compass is so placed as to be free from the effects of vertical iron (which, now-a-days, is seldom the case), it is possible, by comparing the natural deviation on the north and south points with that on the east and west, to determine pretty accurately the direction of the ship's head at time of building; *or, knowing this*

* When, on the other hand, a compass is flanked by a donkey boiler, or the iron pedestal of an engine-room telegraph on the bridge, compensation on the North and South points would be necessary.

Diagram No. 7.

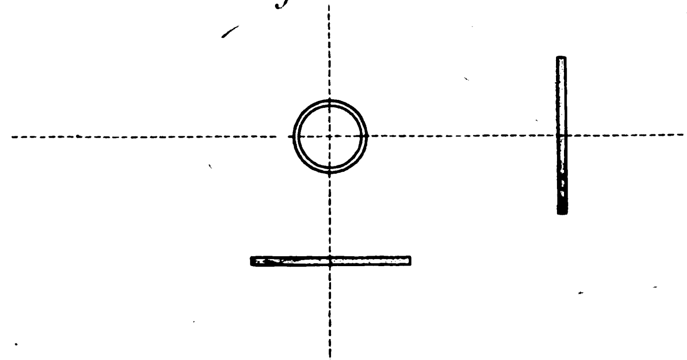

Diagram No. 8.

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*latter and the natural deviation on north and south, it is possible to determine how much of the deviation on east and west is due to sub-permanent magnetism, and how much to the induced magnetism of vertical iron. This knowledge is very important.**

Quadrantal Correctors.

When the ship's head is either N.E., S.E., S.W., or N.W., the remaining deviation (quadrantal) is got rid of by cylinders, or better still, by hollow globes of cast iron, placed on each side of the compass bowl. Where large masses of iron are unsymmetrically placed, as in the case of turrets in echelon, or where the compasses are not in the amidship line of the ship, the quadrantal correctors, instead of being in the true 'thwartship line, have often to be placed obliquely.

Should the sign of the co-efficient D be minus, the correctors would have to be placed in the fore and aft line.

How to place magnets.

The athwartship and fore-and-aft magnets are usually, but not necessarily, placed on the deck *below* the compass. Sometimes it is more convenient to place them on the deck *above*, or on a bulkhead, or inside the binnacle itself. In reality, it matters not whether they are placed above or below the compass, so long as the middle of the magnet's length is in the vertical plane, passing fore-and-aft or athwartships—as the case may be—through the centre of the compass card. (*See Diagram No.* 7.)

On no account are *steel* magnets to be applied *end on* to the compass, neither should they be placed vertically, excepting the one used for correcting the heeling error. Therefore, athwartship magnets must be placed either before or abaft the compass, and fore-and-aft magnets to starboard or port. In other words, they should be applied "broadside on."

Size of magnets and distance from card.

It is preferable to use large magnets at a considerable distance, than small ones close to. The rule is, that the magnet should not be nearer to the centre of the card than twice its own length; thus, a 30″ magnet should not be within 5 feet. But some are so weak that at this distance their effect would be next to nothing. Well-made magnets of equal size will sustain each other's weight

The rule as given by Lieut. A. Collet of the French Navy is—"The distance of the corrector magnets from the card should be such that the perpendicular, from the middle of the bar magnet

* Rule: Enter the traverse tables, with the correct magnetic direction of the ship's head at time of building, as a course. In the departure column look for the number corresponding to the deviation on north or south, and against it in the latitude column will be found the value of the sub-permanent magnetism on east or west, which, subtracted algebraically from the quantity actually observed on one or other of these points, will leave the amount due to vertical iron.

to the line that joins this middle to the centre of the needles, may cut the plane of the needles at a distance from the centre, equal at least to six times the length of the needles." *

How to place Quadrantal Correctors.

The cast-iron cylinders or globes—on suitable brackets—are placed on each side of the bowl, *so that their centres may be as nearly as possible on the same level as the compass needles*, and mostly that a horizontal 'thwartship line through the centre of the card may pass through their centres also. (*See Diagram No.* 8.)

How to place vertical iron pillar.

The wrought-iron vertical pillar ("Flinder's bar") is generally from 3 to 4¼ inches in diameter, and of such a length that, when secured in its place, the *upper* end may be about 2 inches or so *above* the level of the card. It is more usually placed on the *fore side* of the compass, and exactly in a direct fore-and-aft line with the centre of the card; but cases may arise where the balance of effect of the ship's vertical iron lies *itself* on the fore side of the compass, in which case the compensating pillar might have to be placed on the *after* side. The rule is simply this—that the pillar must be placed so that the pole on a level with the compass card may be of such a name as will counteract the pull of the ship's vertical iron; and to accomplish this, the pillar may be placed in various positions, being sometimes on the same and sometimes on the opposite side to the force it is intended to compensate. Occasionally it will be found necessary to bolt it to the deck overhead (as in a wheelhouse), so that its *lower* end may hang a couple of inches *below* the level of the card. A good example of this kind of adjustment is shewn facing page 601.

Admiralty method originally in use.

In the Admiralty method of adjusting the sub-permanent magnetism, only *one* magnet is used. This is placed horizontally with the middle of its length exactly under the centre of the card, at such a distance from it, and at such an angle with the fore-and-aft line of the ship as will produce the desired effect. The explanation of its action is simple:—it is merely the *resultant* of the forces which affect the needle when the two magnets—one athwartships and the other fore-and-aft—are employed.

This is a very elegant method, but somewhat more difficult than the ordinary one in vogue on board merchant vessels. For details see *Bedford's Sailors' Pocket-book*, p. 48, 6th Ed.

When intending to adjust, choose a fine day with smooth water,

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* *Practical Guide for Compensation of the Compass Without Bearings.* Griffin & Co., Portsmouth, 3s. 6d.

provide a number of steel magnets of various sizes,* and mark their centres. Hold them one by one near a compass, and a couple of inches or so of that end which attracts the north end of the needle, paint blue, and the other end, red.

Preparations previous to adjusting.

It will also help matters to tint red the northern semicircle of each compass card, and its southern half blue. This can be done with the ordinary coloured pencil. It will do no harm to allow it to remain so always, and, indeed, compass cards might with advantage be coloured this way by the makers in the first instance.

Plumb under the centre of the compass, draw on the deck two chalk lines, one fore-and-aft and the other athwartships, as represented in *Diagram No.* 7. In the case of a wheelhouse compass, do the same *on the underside of the deck overhead.* We will suppose the vessel to be at sea, and that it is intended to use the bearing of the sun.† Work up the position from last observations, and set your hack watch to *Apparent Time at Ship,* as explained in the chapter on the Pelorus. Take from the Tables the sun's *true* bearing for every four minutes of the time during which you will be occupied adjusting, and convert it into the *Magnetic* bearing by applying the Variation at place, taken from the *Variation chart,* and duly corrected for annual change, which latter in some parts of the globe is too large to be neglected. Write down neatly, in a small pass-book, these Magnetic bearings and corresponding times.

Draw chalk lines on deck.

Set watch to A.T.S.

To find the Magnetic bearing from the true, you must apply westerly Variation to the right, and easterly to the left. Thus, if the *true* bearing be East, and the Variation two points westerly, the *Magnetic* bearing will be E.S.E.

Make list of sun's magnetic bearing.

If a steamer—take in all sail, *trim her perfectly upright* by filling the boats with water or otherwise, slow the engines so as not to waste coal, provide copper tacks and a hammer, *and see that the lubber-lines of the compasses to be adjusted are truly fore-and-aft.* Place the Pelorus in one of its stands—near to the man at the wheel, if possible—and appoint an officer who has some "Nous," and is thoroughly familiar with the instrument, to put the ship's head as required, whilst attending yourself to the compasses. Begin with the Standard, being the most important,

Lubber lines truly fore-and-aft.

* Magnets for use on board ship are usually soldered in watertight cases of copper, to protect them from rusting.

† The writer, over 30 years ago, using the *moon* for this purpose, adjusted a new steamer at night in the Sunderland Dock, much to the astonishment of the natives.

and leave the Steering compass to the last; although there is no reason why its deviation on the various points, as the ship goes round, should not be noted by another officer. All being ready, let the lubber's point of the Pelorus be secured at North, and the sight vanes clamped to the sun's Magnetic bearing, then starboard or port the helm until the sun's reflected image is seen in the speculum or mirror fairly bisected by the thread of the vane.

How to use Pelorus.

The vessel's head will now be North *Mag*—that is to say, in the direction of the north magnetic pole, as would be indicated by a well-made compass in a wooden ship without a particle of iron on board, either in her construction, equipment, or cargo. If, now, the compasses were correct, they would agree with the Pelorus in shewing the ship's head to be North; if, however, influenced by the iron of the ship, they fail to do so, the amount that each differs from it will be the *Deviation* due to that particular compass *on that particular course.*

To adjust on North.

Accordingly, if the north or red end of the compass-card be attracted—say three points to starboard—the ship's head will appear N.W. by N. by compass; or in other words, the deviation will be three points easterly (+). To counteract this blue *attracting* force of the Sub-permanent magnetism on the starboard side, place athwartship on the deck—either before or abaft, above or below the compass, as most convenient—a steel magnet, *with its red end to starboard,* and, consequently, *its blue end to port of the compass.* The red end of the magnet will of course repel the red end of the needle *from* the starboard side, and be aided in doing so by the equally strong attractive force *to* port of the blue end of the magnet.

To avoid setting up a swinging motion, let the magnet at first be placed a considerable distance from the compass—say four or five feet—and put its centre mark exactly on the fore-and-aft chalk line. Then move the magnet gradually closer, until the ship's head is North by the card.*

The pull of the starboard side will now have been neutralized by the combined action of the poles of the magnet, which may be lightly tacked down in its place. This is shewn in *Diagram No.* 9

* It is convenient to keep in the pocket a small magnet jointed like a pair of dividers. When closed the opposite poles touch and neutralise each other: when open the magnet can be applied adroitly above the compass card to bring it to rest. One leg (N.) should be painted red, the other blue. *Be careful to close this gentleman the very moment you have done with him.*

Diagram No. 9.

SHIP'S HEAD NORTH, MAG:

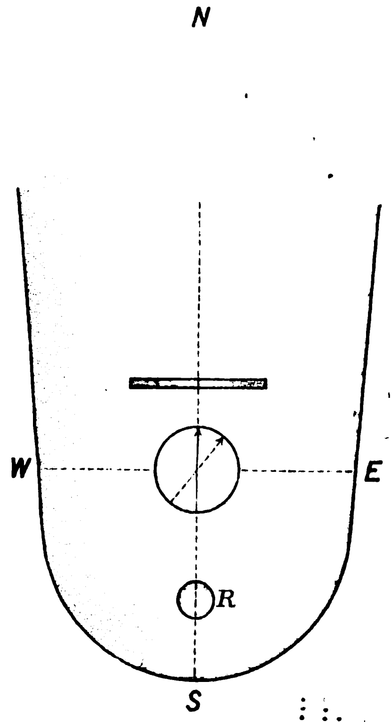

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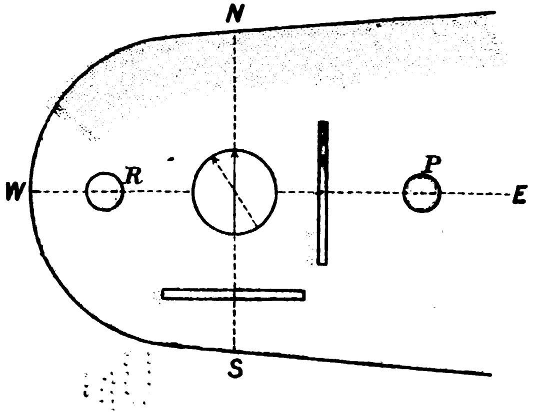
Diagram No. 10.

SHIP'S HEAD EAST, MAG:



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Adjust each of the other compasses in a similar manner, placing the red or *repelling* end of the correcting magnet to starboard or port, according as the north end of the compass-needle is *attracted* to starboard or port by the ship. If one magnet be insufficient to correct the Deviation, apply another—putting it, if possible, on the opposite side of the compass to the first; or, if the first be on the deck *under* the compass, the second may, if desired, be tacked to the deck *above* it. *But in every case similar colours must point in the same direction, or they would neutralize each other.* All this time the officer at the Pelorus—duly provided with watch and pass-book—is altering the setting of the sight vanes for every half degree of alteration in the sun's bearing, and is conning the ship *with small helm,* so as to keep her steady on the North point (M.), signalling by whistle whenever she is exactly so.

Having taken a second look at each of the compasses, and made any little alteration which may be required, screw the lubber line of the Pelorus to East; and, keeping the vanes set to the sun's M. bearing, bring the ship's head round with port helm until the sun's image is once more seen in the speculum, and *steady her* carefully on this fresh course. The various compasses, if correct on this point, ought *also* to show the ship's head as East. Should they fail to do so, the difference is the Deviation, which must be corrected *partly* by fore-and-aft magnets of steel, and *partly* by the Flinder's bar. **To adjust on East.**

The means taken to determine *how much* is to be corrected by one, and how much by the other, will be shewn further on; in the meantime, imagine half the deviation to be corrected by the pillar and half by the steel magnet. If now, with the ship's head at East (M.), the needle be drawn two points towards the stern,* the ship's head by compass will be E.S.E. To counteract this, place a steel magnet fore-and-aft ways, either to starboard or port of the compass, with its red end *also* towards the stern, and centre mark on the 'thwartship chalk line. Move it slowly towards the compass till half of the westerly Deviation is corrected. The ship's head will now be E. by S. by compass. Next place the Flinder's bar *forward* of the binnacle at such a distance as will cause the ship's head to appear due East, when it may be securely bolted down to the deck. It is preferable, however, that the lower end of the pillar should be let down some distance *through* the deck, and rest either on the one below, or on some firm sup-

* When speaking of the needle being attracted or repelled, its *north* end is always meant, unless otherwise specified.

port provided for the purpose. The object is not only to intensify its power, but to keep the *lower* pole of the pillar from being so near as to counteract the opposite effect of the *upper* one. The compass at this stage is shewn in *Diagram No.* 10. *R* stands for the rudder post, which in this case is the active vertical iron, and *P* for the pillar which is intended to counteract it.

The *Semicircular* deviation of all the compasses is now corrected. We have still, however, to deal with the *Quadrantal.*

To adjust on N.E.

Put the ship's head *by Pelorus* on any one of the four principal inter-cardinal points—say N.E. correct magnetic. In 99 ships out of 100 the compasses will exhibit *Easterly* Deviation on this point, amounting to as much sometimes as 10° or 12°. Should this be the case, a cast-iron cylinder or globe must be placed on each side of the compass-bowl, and moved nearer to or further from it, till the ship's head points correctly to N.E. *by compass* also.

This adjustment, once properly made, does not require touching ever after, unless, indeed, the ship were to load a cargo of iron, or some alteration made in the iron-work near the compass.

Rule as to placing Quadrantal Correctors.

The ends of the correctors must not, however, be nearer to the centre of the card than 1¼ times the length of the longest needle, so that they may effect their purpose by becoming magnetic by *terrestrial* induction, and not by the inductive influence of the compass needles. If placed too close, the inductive effect of the needles upon the correctors will be greater than the inductive effect of the earth, and their reciprocal action on each other would be excessive, resulting in error—notably *octantal* error; secondly, the magnetic field would not be uniform.*

Looking at Diagram No. 11, it will be seen that the *port* ends of the cylinders exhibit *red* magnetism, and in this position compensate *easterly* Deviation; but on turning the ship round to N.W., their *starboard* ends acquire red magnetism, and in this fresh position compensate *westerly* Deviation. Chain boxes, though in very common use for this purpose, are not to be recommended. The best corrector of Quadrantal Deviation is a couple of hollow cast-iron globes or shells, the introduction of which, like many other things sailors have to be thankful for, is due to Lord Kelvin.

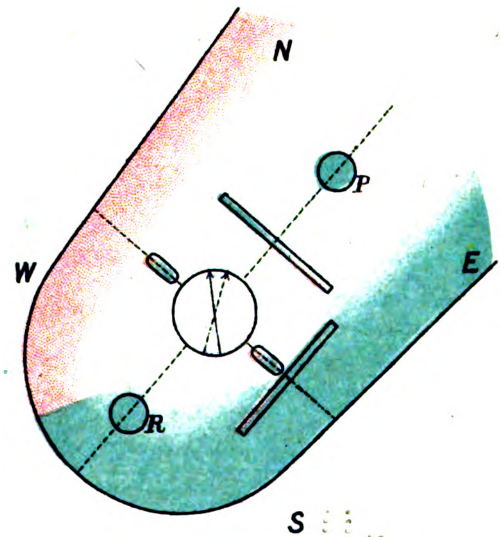
Magnetic effect of hollow iron.

Here may be mentioned incidentally a curious and often-times important fact with respect to all hollow iron bodies, whether

* The magnetic field is the space surrounding a magnet in which such magnet exercises its influence, and uniformity supposes the lines of force to be parallel.

Diagram No. 11.

SHIP'S HEAD N.E. MAG.



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globular or square, such as water-tanks, &c.—namely, that as soon as the thickness of the sides has reached to $\frac{1}{10}$ of the thickness or diameter of the whole body, the magnetic effect is the same as if the body were a solid piece of iron.

Semicircular and Quadrantal Deviation, why thus named.

The compass is now shewn fully adjusted in *Diagram No.* 11.

Semicircular Deviation is so termed because it has the *contrary name* and maximum value in *opposite semicircles*—thus, if it is easterly on North, it will be westerly on South. On the other hand, *Quadrantal* Deviation is so termed because it is greatest on the four inter-cardinal points. It has the *same name* in *opposite quadrants* and the *contrary name* in *adjacent* quadrants. Thus, if it is easterly on N.E., it will be easterly on S.W. also, but westerly on S.E. and N.W. So you see the two kinds of Deviation are vastly different.

Variable effect on compass needle of compensating Magnets.

Steel *fore-and-aft* magnets produce their greatest effect on East and West, diminishing to nothing on North and South, when they become parallel to the compass needle. A Flinder's-bar placed on the centre line before or abaft the compass acts in the same way. Steel *'thwartship* magnets produce their greatest effect on North and South, diminishing to nothing on East and West, when they become parallel to the compass needle.

Variable effect of Quadrantal Correctors.

Quadrantal correctors produce their greatest effect on N.E., S.E., S.W., and N.W., tapering off to nothing at North and South, East and West. When the ship's head is on North or South (M.), the poles of cast-iron cylinders, being at right angles to the "line of force," are powerless to affect the compass; and when the ship's head is on the East or West (M.), though the cylinders are then magnetic, they cannot affect the compass, as their poles are parallel to the needle. In the case of cast-iron globes, their magnetic poles are parallel to the needle on all four of the last-named points, but the effect is the same as with the cylinders.

Any one following out this system of compensating magnets, with its ever-varying effects, cannot but be struck with the beauty of the arrangement which permits of so many discordant elements being made obedient to natural laws.

When the process described above is accurately carried out, and the compasses well made and properly situated, they will be *nearly* correct on *every* point. Nevertheless, it is prudent to steam the ship completely round, steadying her on every fourth point by Pelorus, to determine remaining errors.

Then, should any compass be found to have considerable deviation—say 4° or 5°—on the *opposite* points to those on which it

Final corrections.

has been adjusted, *halve the error between the two.* If, for example you find a compass correct on North, but 4° out on South, move the 'thwartship magnet so as to reduce the error on South to 2°, which will, of course, cause 2° of error on the North point also. When necessary, do the same on the West and S.W. points likewise. After which, swing ship for a table of remaining deviations on every *second* point. When this inequality occurs, it shews that the ship's iron is not symmetrically distributed round about the compass in question.

Having finished up, resume Course, nail the magnets down for good, and cover them at your leisure with neat cases of hardwood.

Sea Adjustment preferable to Dock Adjustment.

If the operator knows what he is about, adjusting in this manner should not occupy more than from two to three hours, and is worth a hundred swingings in a close dock, where there is probably any amount of *Local Attraction* by cranes, bridges, roof girders of sheds, water pipes, &c., not to speak of other metal vessels round about.

Caution as to Steam Tenders and Tugboats.

Few people are alive to the fact that in high latitudes even a *wooden* tugboat may be a source of trouble to the compass, if, when fast alongside, the upper end of the funnel, as will probably be the case, is about the level of the bridge or Standard compasses, and not many feet from them. An instance of this occurred to the writer in Queenstown harbour, when the Standard compass of his ship was affected to the extent of 3° by the funnels of the passenger tender. Thus an apparently trivial cause might lead to serious results, and shews the necessity for being *continually* on the alert.

Flinder's-bar.

It is now necessary to go back a little, and explain the manner of getting at the *correct* amount of Deviation to be compensated by the Flinder's bar. When the ship's head is either East or West, any deviation then existing arises partly from Sub-permanent magnetism resident in the bow and stern (which must be compensated by a permanent steel magnet), and partly from the induced magnetism of vertical iron predominating more at one end of the ship than the other. This latter must be compensated by a like cause applied in the opposite direction. Thus, if vertical iron situated *abaft* the compass pulls the needle towards it, another piece of vertical iron can be put *forward* of the compass to pull it back again; or it may even be placed *abaft* the compass, on the same side as the disturbing force, if the deck fittings will permit of its *repelling* pole being placed on a level with the card.

It has been shewn that on the Magnetic Equator vertical iron ceases to be magnetic, and is consequently powerless to affect the compass. *If, then, the Deviation be ascertained on the cardinal points when the ship is on the Magnetic Equator, it is certain that it cannot be due to vertical iron.* It must be owing either to *Sub-permanent* magnetism, or to "Retained" magnetism, to be explained hereafter. For the present let us assume that it is Sub-permanent only, and correct it by a steel magnet; which being done, let the vessel proceed to high latitudes, and let the Deviation be again determined. Then, that arising from Sub-permanent magnetism having already been cured on the equator, and being, moreover, *when compensated,* not sensibly affected by change of geographical position, we know that whatever now exists is principally due to vertical iron, and should therefore be corrected by a vertical iron pillar, applied as already explained. In practice, the experiment on the equator is only tried on the East and West points, as vertical iron, from its symmetrical arrangement in the ship, seldom disturbs the compass on the north and south points. **How to know the amount of Deviation to be corrected by vertical pillar.**

Again, supposing a vessel to have been built with her head due North: this will have constituted her a Sub-permanent magnet, whose axis lies exactly fore-and-aft, the bow being the red, and the stern the blue pole. When such a ship is placed head East, the red bow repels the needle, causing westerly Deviation; and unless she proceeds to the Magnetic Equator, there is no way of telling how much of it arises from the cause just mentioned, and how much from the induced magnetism of vertical iron.* **Effect of ship built head North.**

On the other hand, suppose the ship's head to have been due East when building, then the port side would mostly be Sub-permanently red, and the starboard side blue. Now, what Deviation would this cause when the ship's head was East or West at any after time? None whatever. Since the poles of the ship's Sub-permanent magnetism and the needle itself would lie in the same straight line, *the only effect would be to diminish or increase the directive force of the needle.* Nevertheless, on trial there is found to be large Deviation on these points. If so, it must be due to masses of vertical iron situated either before or abaft the compass, according to the direction of the pull, and is capable of easy cure by one or more Flinder's bars applied in the proper manner. **Effect of ship built head East.**

There is another point in connection with the *diminished*

* This is the extreme case (never likely to occur), which is put to give more point to what follows. Ordinarily, the rule given in the footnote on page 591 would be used.

Diminished directive force —sluggish Compasses.

directive force of the needle which should not be overlooked; namely, that when the ship is steering in the same direction as that in which she was built, the compass, *when uncompensated,* will be both sluggish and fickle. Therefore, every master of an iron ship should endeavour to learn in what direction his ship was built, and, when sailing on that course, be more than ever on his guard against the seemingly mysterious pranks of his compass.

Example of difficult Compass Adjustment.

The forward wheelhouse compass of the s.s. "————" commanded by the writer, from its extremely bad situation, affords a good example of difficult compass correction. Previous to adjustment, this compass—although an excellent 12″ liquid one, by Cairns of Liverpool—had enormous natural deviations. *Diagrams* 12 *and* 13, drawn to a scale of 0″·3 to the foot, shew the steps taken to correct it.

Iron mainmast a magnet.

From the very close proximity of the mainmast, which acted as a powerful magnet, it was evident from the outset that strong measures would have to be taken with this compass. Experiment shewed that, at the level of the card, which was below the "neutral point" of the mainmast, the latter had north or red polarity, and exerted a strong repellent action on the needle.

Separating Inductive and Sub-permanent magnetism

In due course the ship was swung, and her *natural deviations* carefully ascertained all round. Having been built with head N. 68° E. (M.), the deviation on north should have been twice and a half as much as that on east, *were the compass undisturbed by vertical iron.** Knowing what it actually was on both these points, it became a comparatively easy matter to roughly separate the Inductive from the Sub-permanent. Accordingly, two round bars of wrought-iron, each 4″ in diameter, were used to counteract the mainmast. The after one—48″ in length—was let down through the top of the wheelhouse, and the other—42″ in length—was bolted to the deck just abaft the mast.

It will be noticed, on looking at *Diagram No.* 13, which represents the ship's head in an easterly direction, that the north end of the needle was forcibly *repelled* by the mast. Now the *upper end* of the vertical pillar between the compass and the mast strove to *pull* it back again, and in this it was aided by the *lower end* of the pillar abaft the steam-steering wheel, which repelled or pushed it back in the same direction. The distance of these pillars from the compass was so arranged, that when in position, they about compensated the deviation due to the in-

* *Vide* Traverse Tables.

Diagram No. 12. SIDE ELEVATION

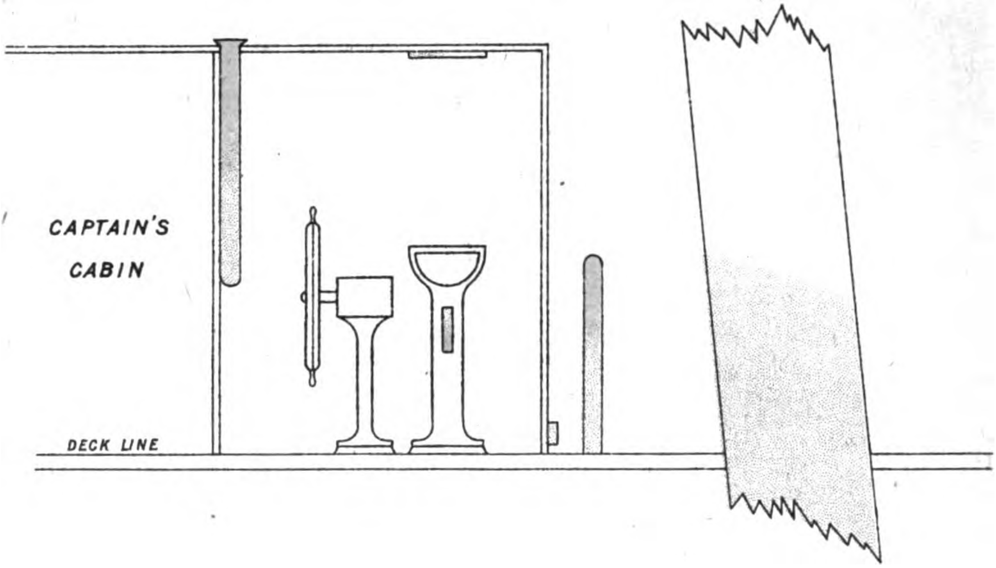
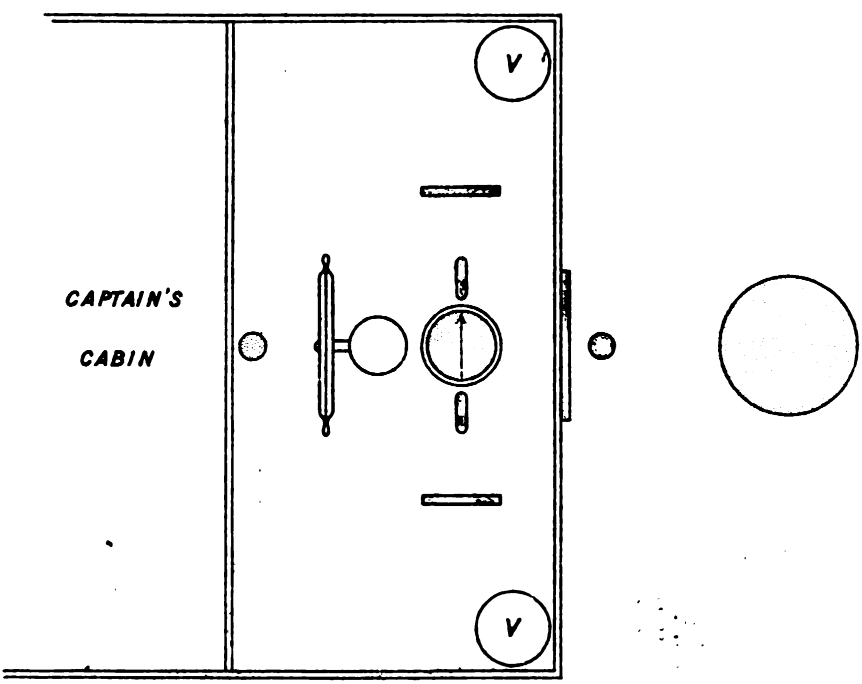


Diagram No. 13 GROUND PLAN



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ductive magnetism of vertical iron; the remaining deviation on the east and west points was corrected by two 16″ steel magnets, tacked on fore-and-aft ways to the *under side* of the deck *above* the compass. The deviation on north and south points was compensated by one 30″ 'thwartship magnet tacked on to the outside of the forward bulkhead; and the *Quadrantal* deviation (10°) by two cast-iron cylinders with globular ends, something like the old-fashioned clock weights, each being 12″ long by 3¼″ in diameter.

This formidable array of magnets reduced the huge errors of the compass within more manageable bounds, but afterwards, when at sea and the ship listed over, the heeling error was excessive, and had to be compensated in the usual way, by a *vertical steel magnet*, placed exactly under the centre of the card when the vessel was upright. Two iron ventilators marked V were also removed. Nevertheless, this compass was extremely wild and fickle during the first and second voyages, and although it afterwards behaved somewhat better when the ship's magnetism had settled down, it could not be said to give very satisfactory results at any time. Of course the builders should never have placed the wheelhouse in such a ridiculously unsuitable place; but being there, and no way of improving matters short of putting in a wooden mainmast, it was necessary that the Captain should know how to make the best of a bad job. **Heeling error.**

The reader will perceive, from the very unusual character of the conditions named, that in the case just quoted, the amount of deviation to be compensated by the Flinder's bars could only be approximately inferred; and it is probable that, if ever this ship went down to the Magnetic Equator, some little alteration of these arrangements was found advisable.

To avoid confusion of ideas, it has been considered wise to leave for separate consideration that part of the ship's magnetism which is known by the term "Retained." It plays, however, a very important part in the deviation of compasses, and will be found to modify to some extent what has been said in the previous pages. It belongs to the *semicircular* order of deviation. **Retained magnetism**

It has been stated that when the kitchen poker is held in the "Line of force," it *instantly* becomes magnetic; or more correctly, that the latent or dormant magnetism within it has undergone excitation when held in that particular manner. This statement is correct so far as it goes, but it is necessary to supplement it by saying, that the longer the poker is so held, the more magnetic it becomes—up to a certain point. Again, when the poker is held at right angles to the "Line of force," it loses its magnetism; but if it has previously stood *for a long time* in the "Line of force," it will not lose it instantaneously, but will require a longer or shorter period to get rid of the magnetic charge, according to its intensity, and the quality of the iron in which it was excited—soft iron parting with it more readily, and *vice versâ*.

Now this is just what happens when a ship's head has been in one direction for a long time. She becomes temporarily magnetised by the earth's inductive force, and this action is intensified by the sea striking her; and also, in the case of a steamer, by the tremor imparted to the hull by the engines. The poles of this magnetism are of course parallel to the Magnetic Meridian. Thus, if the ship sailed due south for a week or so, her stern would acquire red and her bow blue magnetism—the new charge being superposed on what may be called the ship's *natural* magnetism, and, to a certain extent, masking it.

Duration of Retained magnetism.

"Retained" magnetism remains for a considerable time after the cause is removed—frequently for days—unless the direction of the ship's head be exactly reversed, when it goes more quickly, giving way to the opposing influence of the magnetism proper to the new direction of the ship's head.

This is a *most important phase* in the magnetic character of a ship, and any one who chooses to investigate it will see, *that for this reason alone* an Adjuster's *Deviation Table* is comparatively worthless. Thus, if a ship has been lying up in a dock—say head south for several months, or even weeks—and was then most carefully adjusted, and replaced in her original berth to load for sea, but with her head in the reversed direction, it would be found before sailing that her compasses had comparatively large deviations, though when the adjuster left the vessel a fortnight previously they were practically free from error. Every one entrusted with the navigation of an iron ship should keep this fact continually before him.

Retained magnetism — effect when course is changed.

The immediate effect of "Retained" *magnetism* upon the compass of a ship at sea is to cause her, on a change of course, *to deviate invariably in the direction of the last one.* If a vessel has been steering—let us say South—for some time, and is then hauled-up West, it will be found that the deviation previously existing on that point will be increased

Tendency towards last course.

if it has been westerly, and diminished if easterly—*the change frequently amounting to a point and upwards;* so that, unless allowed for, she will infallibly be thrown to the southward of her intended course. Even in shaping a fresh course, differing only

Effect of Retained magnetism entering New York Bay.

a couple of points from the last one, this propensity of the compass must be taken into account according to circumstances, as it varies much in different ships, and in different compasses on board the same ship.

As an illustration, we will take the case of the lines of steamers running constantly between Liverpool and New York or Philadelphia. On the outward passage these vessels have their heads in a westerly direction for upwards of a week, and consequently the poles of their "Retained" magnetism lie to starboard and port—the red pole on the starboard, and blue pole on the port side. The tendency on subsequent northerly courses will be to throw the ship to the westward. Thus, entering New York Bay by the south channel, the Swash Range Lights come in one bearing N. $40\frac{1}{4}°$ W. (M.); but if, when in one, the vessel be steered directly for them, the direction of her head *by compass* will probably be about N. 33° W., or even more to the northward. The same effect will be still better shewn when hauled up for Fort Hamilton. The Main Ship Channel course, keeping the Range Lights in one astern, is N. $13\frac{1}{2}°$ E. (M.), but the chances are in favour of the vessel having to steer about N. 23° E. *by compass*, or, at all events, considerably to the eastward of the proper course. Much depends on the situation of the compass.

The same thing occurs in the Delaware. From Cape Henlopen to the Brandywine Lighthouse, the course—keeping the ranges in one astern—is North (M.); it is quite common, however, to steer about N. 12° E. by compass.*

Effect of Retained magnetism in Irish Channel.

On the homeward passage, these steamers, having had their heads to the eastward for a week, get magnetised in the opposite direction. It is the *port* side which now has *red* magnetism; and in consequence, when hauled up at Tuskar for the Skerries or South Stack, instead of steering N. $56\frac{1}{2}°$ E. (M.), they have generally to shape a *compass course* many degrees to the northward.

How to eliminate Retained magnetism.

As the effects due to crossing the Atlantic are about equal, going and coming, it is not a difficult matter to adjust the compasses with accuracy for the ship's Sub-permanent magnetism on the North and South points. If, for example, outward bound, with head North by compass in the Delaware, the deviation is found

* In Trans-Atlantic Steamers it is a good plan to have one of the deck compasses adjusted for the American port frequented, and another for the English port. The writer used to keep his Bridge compass adjusted for the Delaware inward-bound, and the Standard or Navigating compass for the Irish Channel, outward-bound.

How to treat "Retained" in N. Atlantic.

to be 8° *westerly;* and homeward bound, with head North outside Queenstown, it is found to be 20° *easterly*—the amount of *Sub-permanent* magnetic attraction to be compensated by the 'thwart-ship magnets is 6° easterly. Accordingly, at one or other of these places the magnets should be moved to show 14° of deviation—westerly in the Delaware, easterly at Queenstown; *and this amount would then be solely the effect of* "Retained" magnetism, which would quickly disappear if the circumstances producing it were reversed.

It is evident that were it due to *Sub-permanent magnetism*, it could not, on the same point, be easterly at one time and westerly at another. But, in making these observations and corrections, *do not forget that the ship must be perfectly upright, or the results will be vitiated.* From half passage over either way, it will be easy to adjust on the East and West points, as by that time the "Retained" magnetism due to steering towards the North or South will have disappeared.

Over compensation of Quadrantal Deviation.

No possible amount of care or scientific knowledge in an adjuster can provide against "Retained" Magnetism. There is, however, one dodge by which its effects can, in some minor degree, be modified. In those regular liners always sailing on the route just specified, it will probably be found useful to *over*-compensate *the Quadrantal deviation.* The correctors diminish westerly deviation in the N.W. quadrant, and easterly deviation in the N.E. quadrant; therefore, by *over*-compensation, the effect of the Retained magnetism would be partially neutralized in one semicircle of the compass at both ends of the voyage; and so long as the course lay within that semicircle, there would be undoubted advantage. On the other hand, those liners who run principally in a North and South direction, and have occasion to make abrupt changes of course near the end of the passage, should have their Quadrantal deviation *under*-compensated, or, if small, neglected altogether.

These last are not so fortunately situated as the first named, since the application of correctors for Quadrantal deviation has not only the effect of increasing the directive force of the needle, but lessens very considerably the error due to heeling (*vide* page 612).* Each one, therefore, must judge for himself how far these suggestions are suitable to his own particular route and ship. Pole compasses, *when well placed,* are comparatively ex-

* The Quadrantal deviation in all these cases is supposed to be of the kind due to the co-efficient + D; that is, easterly in the N.E. and S.W. quadrants, and the contrary in the other two.

empt from the effects of Retained magnetism, and Masthead compasses are almost entirely so.

Now this matter of "Retained" *magnetism* has a very important bearing upon compass adjustment. It is evident that if its effects get mixed up with the ship's *permanent* or *congenital* magnetism, the adjuster will be compensating something which would ultimately have disappeared of itself, or perhaps even have taken an opposite name. This is another reason why a *Deviation Table* cannot be trusted, and by imparting undue confidence, is more likely to lead into trouble than to keep one out of it. It shews also that, before the Captain of a ship undertakes to meddle with his compasses, he should be tolerably certain that they are free from this fleeting but troublesome error, or else know by experience how much to allow for it.

Irish Stew

If, soon after launching and masting, a ship be experimentally swung for compass errors, and then be completed for sea with her head in the opposite direction to that which it had whilst on the building slip, it will be found on next swinging her that a wide discordance will exist between the first and last Deviation Tables. Now, as already stated on page 587, an iron ship becomes a magnet during the process of construction, but only a portion of the magnetism thus acquired is fixed or *Permanent*, the remainder is of the "Retained" type; and to get rid of this surplus charge before the compasses are adjusted for sea, it is highly expedient that an iron vessel should have the direction of her head reversed as soon as possible after she leaves the stocks, *and kept* so till she is taken away to be adjusted. This unfortunately is too often neglected, as builders generally are averse to the trouble, or it may not always suit their convenience in other respects. But, seeing its great importance, owners ought to make reversal obligatory by inserting a clause to that effect in their specification, for instance, that the vessel should have the building direction of her head reversed for at least ten days previous to adjustment. When reversal is neglected, the adjustment made just before going to sea is only so much time and money scattered to the winds, not to speak of the positive danger likely to accrue from the omission if the vessel should have a beating wind and thick weather when going down channel.

First Adjustment of new vessels.

Reversal after launching.

The writer has a lively remembrance of a case in point. Not a hundred years ago it was his fortune to command a fine new steamer, which the builders, in spite of all entreaty, refused to reverse after launching. When the day for it came, the adjustments were carefully made by himself and a professional of considerable reputation. The vessel then started on a trial trip which lasted some 36 hours. During the greater portion of this time, however, the writer was kept briskly on the move, shifting magnets and readjusting according as the vessel parted with her "Retained" magnetism. No doubt the builder, in his happy ignorance, thought the extra fuss was all a "fad" of the Captain's. Luckily, throughout the trip, the weather was beautifully clear and the sea like a mirror, but had it been thick and stormy, that builder might have left the ship in a sadder, if not a wiser, mood.

The Latin proverb, when paraphrased, tells us that experience teaches even *wise* men.

Facilities for adjustment of Eastern going steamers.

The numerous lines of steamers running to Eastern ports through the Suez Canal have a splendid opportunity for adjusting their compasses in the most perfect manner. In the first place, between Aden and Ceylon—a distance of over 2000 miles —*they are steaming nearly due East on the magnetic equator,* during which time, of course, vertical iron has no effect whatever on the compass. Therefore, when about half passage over, let the ship's *Sub-permanent magnetism* be carefully compensated with fore-and-aft magnets of steel on East (M.).

As, however, the deviation existing on the east course may be due partly to the ship's *natural magnetism,* and partly—though in a less degree—to the *Retained* magnetism picked up coming down the Canal, Gulf of Suez, and Red Sea, it will be proper, at the same place, on the return passage, to ascertain the deviation on the West point. Should there be any, it ought to be reduced one-half, by shifting one of the fore-and-aft magnets in the required direction, and when the ship gets up by Beachy Head or Dover, *again* determine the deviation on the East point.

How to arrive at amount of deviation due to vertical iron

It may now be pretty large, *and if not mixed up with Retained magnetism, will be due wholly and solely to the influence of vertical iron. Now* is the time to place the Flinder's bar, and let it be at such a distance as will compensate all the deviation on East, unless there is reason to believe that some of it arises from that troublesome *Retained* magnetism, in which case allow, say, a couple of degrees to remain. It is not, however, likely that there will be much "Retained" left by the time Beachy Head is reached; but if the weather is fine, you can make tolerably sure by yawing the vessel right off to *South* for 20 minutes or half-an-hour—going slow—and then putting her on East (M.) to be adjusted.

Should the Flinder's bar be made to bolt to the deck on which the binnacle rests, it will be merely necessary to move it nearer to or further from the compass, till the ship's head points to East (M.) by compass as well as by Pelorus. But if, as recommended, the pillar has been made to let down through the deck, you must ascertain *beforehand* the effect, at various distances, produced by it on this particular compass, *taking care that the experiment is made in the same magnetic latitude as that in which it is intended to ship the pillars.*

When the writer was in the s.s. "*City of Mecca,*" this plan was adopted with complete success. The deviation on East was ascertained off Dover, and noted. On arrival in London, a round wrought-iron pillar, 5 feet long and 4½ inches in diameter, was procured, and its inductive power tested as follows. The compass (12-inch card, 4 needles) was taken on shore in the S.W. India Dock, and placed on some cotton bales, at such a height that the pillar stood a couple of inches above the level of the needles. As soon as the card had ceased vibrating, a piece of marline was stretched across the centre of the compass in an east and west direction, *and made fast.* The iron pillar, *which had purposely been left standing on end for some hours,* was next, with the assistance of an impromptu plumb-line, placed *vertically* under the marline, in which position it was of course at right angles to the direction of the needles, and consequently exerting its greatest influence. Having measured the distance of the pillar from the compass—centre to centre—and noted the effect produced, it was advanced—*still under the marline*—a little nearer, the measurement repeated, the effect again noted, and so on. **Experiment with iron pillar.**

The following shews the results, and may be useful to others under similar circumstances, but only as a rough guide, since different qualities of iron, and a different construction of compass, may increase or diminish the values here given. **Magnetic effect of iron pillar.**

Distance. Ft.	in.	Effect. °
7	6	None.
6	7½	1½
4	7¾	3
3	6½	6¼
2	9½	11¼
1	11¼	25

Having by this method determined the distance at which the pillar would compensate the amount of deviation ascertained off

Flinder's-bar of *City of Mecca.*

Dover, a hole was bored in the deck at the same distance from the compass, and the pillar let down until its upper end stood about two inches above the level of the card, and the heel rested on a strong wooden cleat or bracket, screwed to a bulkhead below. The partners were then wedged up with soft wood, and a duck coat put on over all, and painted, to preserve the pillar from rust. The lower portion of the Flinder's bar came into the second mate's bunk, and interfered considerably with his nether extremities, but being an enthusiast in compass adjustment, the intrusion of cold iron was never known to evoke from him even the faintest protest.

This compass was sworn by ever after, so perfect was its behaviour. It quite rivalled the second mate's.

Adjusting on North and South in Suez Canal.

To adjust compasses on the North and South points, there is a capital place for these eastern-going ships in the Suez Canal, Just after leaving Port Said, there is one unbroken "straight" of 26 miles, the Magnetic course down which is S. $2\frac{3}{4}°$ W. the whole way; and as the speed in the Canal rarely exceeds 7 knots, there will be $3\frac{1}{2}$ hours available for adjusting. It is true the vessel's head cannot be put *exactly* on South (M.); but if the 'thwartship magnets are placed to make the compass show S. $2\frac{3}{4}°$ W. when the vessel is pointing straight down the Canal, this will be found quite near enough. You can test by the sun, of which there is mostly a trifle too much in that part of the world.

Port Said.

The next matter is how to get rid of the "Retained" magnetism acquired whilst steaming on Easterly courses in the Mediterranean, which will naturally produce its greatest temporary effect now that the vessel's head is South, or at right angles to its former direction.

It is usual to coal at Port Said; or if a steamer arrives late in the afternoon, it is seldom that she can proceed before the next morning. If, during this unavoidable detention, the pilot can be prevailed upon to put the vessel into the Ismail Basin, she will there head to the N.W.; or in the opposite direction, to the courses steered down from Malta; and will be almost sure to have lost all her *Retained* magnetism before the following morning.

Even should it be found impossible to get the ship's head in this direction, the ordinary berth for waiting steamers runs about S.W., or some 10 points from her last course, which will go a long way to remove the unwelcome visitor. If in any doubt, however, the compasses can again be tried near South, when abreast of Chalouf, or when emerging from the Canal into Suez Bay, by which time they will certainly be free from the effects of the "Retained" acquired on Easterly courses.*

Compensation of Quadrantal Deviation not affected by Retained magnetism.

The compass has now been corrected on the cardinal points, but there is yet the *Quadrantal deviation* to deal with. Fortunately, *in this case* the presence of any amount of Retained magnetism does not signify in the slightest degree. At any convenient time or place, steam the ship right round the circle, steadying her sufficiently long on N.E., S.E., S.W., and N.W. *by compass*, to get the deviation on these points with accuracy. Mark easterly deviation by the plus (+) sign, and westerly by the minus (−) sign, and then proceed as follows:—*Reverse* the sign of the deviation observed on S.E. and N.W., then add together those which have the same sign; take the difference between the two dissimilar quantities thus found, and prefix the sign of the greater. Divide this difference by 4, *retaining its sign*, and the result will be the *Quadrantal deviation*, which, in its natural state, without correctors, will nearly always be + in name; and as it is due to horizontal iron, will retain the same value in any latitude, unless, indeed, the construction of the vessel be materially altered, or large quantities of iron be shipped as cargo. The following example is taken from the Record of the "*British Crown's*" compasses before adjustment.

How to ascertain amount of Quadrantal Deviation.

BELFAST LOUGH. Monday, 6/10/79.

The natural deviation on N.E. was − 6°, on S.E. − 62°, on S.W. + 32°, and on N.W. + 48°.

N.E. − 6°.	S.E. + 62° sign reversed.	+ 94°
N.W. − 48 sign reversed.	S.W. + 32	− 54
− 54°	+ 94	4) + 40
		+ 10° = Quadrantal deviation.

To compensate it; if the sign is + as in the example, put the ship's head the same number of degrees *to the left* of N.E. as the value of the Quadrantal deviation; and, keeping her exactly in this direction by the aid of some other compass, place the correctors, and move them closer to, until her head is N.E. by the

* In *steel* ships, as might be expected, their magnetism is of a more fixed character as compared with iron ones. The Deviations of the compasses in steel vessels are therefore somewhat more constant, which in itself is a great advantage, since in general it is not so much the *amount* of Deviation that is complained of in compensated compasses, as its perplexing variability.

compass under treatment. Ships are so seldom found having Quadrantal deviation with a – sign, that it is unnecessary to enter upon its compensation. It would require the correctors to be placed on the fore and after side of the compass, instead of athwartships.

Quadrantal more embarrassing than Semicircular Deviation.

Although the Quadrantal error is rarely large in amount, like the Semicircular, it is for many reasons very important that it should be corrected. Not the least is the fact, that for the same amount of maximum error, the Quadrantal changes *twice* as rapidly as does the Semicircular error; and, therefore, a Quadrantal error of 10° is much more embarrassing than a Semicircular error of the same amount. The true significance of this will be seen when it is explained that a Quadrantal error of 10° implies a rapid change in the deviation of the compass, amounting to as much as half a point, with so small a change as a point and a half in the ship's course, from one side to the other of any of the four cardinal courses. *Imagine the difficulties of trying to steer by such a compass!*

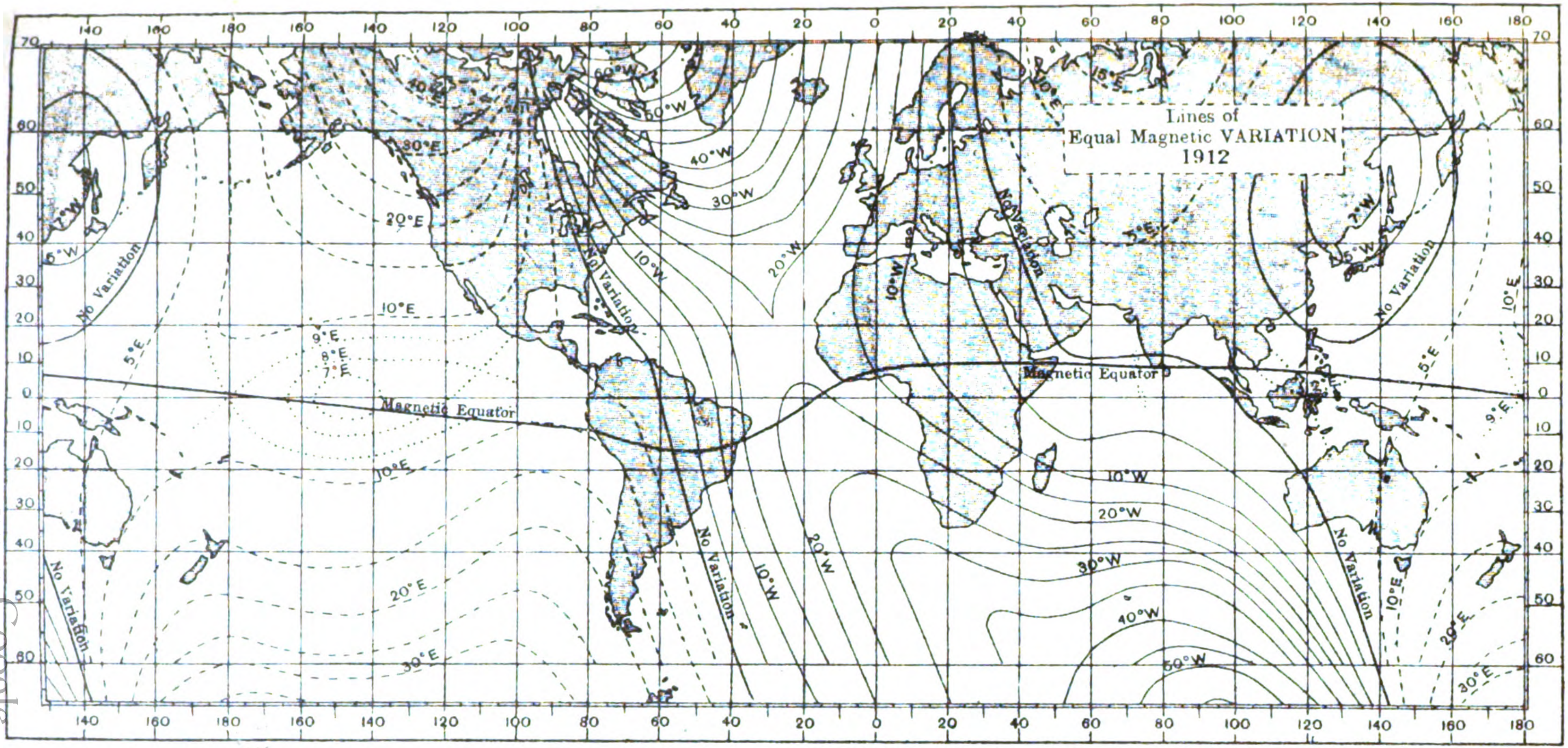
Heeling error.

This concludes the adjustment of a ship *on even beam*, in which only the pull of the *horizontal* portion of the ship's magnetism has duly been considered. Some iron vessels, however, have excessively large deviations, due to magnetic force *below* the compass, since the poles of the ship's magnetism can only lie in the *horizontal* plane in such few ships as have been built on or near the magnetic equator. *Vide* pages 587-588. This heeling error has been known to amount to as much as 2° for every 1° of heel. It is greatest when the ship's head is on the North or South points, and becomes reduced to a very small quantity on East or West. Thus a ship changing her heel from 10° port to 10° starboard, may change her deviation as much as 40°, which no one will deny is a very serious matter.*

Compensation by "Dipping needle."

It is seldom or never possible to list a ship in dock to ascertain her peculiarity in this respect, as doing so costs too much time and money in these days of rapid movements and economy; but it may be approximately arrived at in another and much easier way. Get an optician *of repute* to make you a delicately poised "Dipping needle," mounted on a suitable stand, carrying a couple of spirit levels, and protected with a glass cover. Let the needle-point traverse a vertical scale of degrees, and be fitted with a small sliding balance-weight, so that whatever part of the world you may be in, by moving the weight you can set the needle to zero of the

* See *Appendix.*



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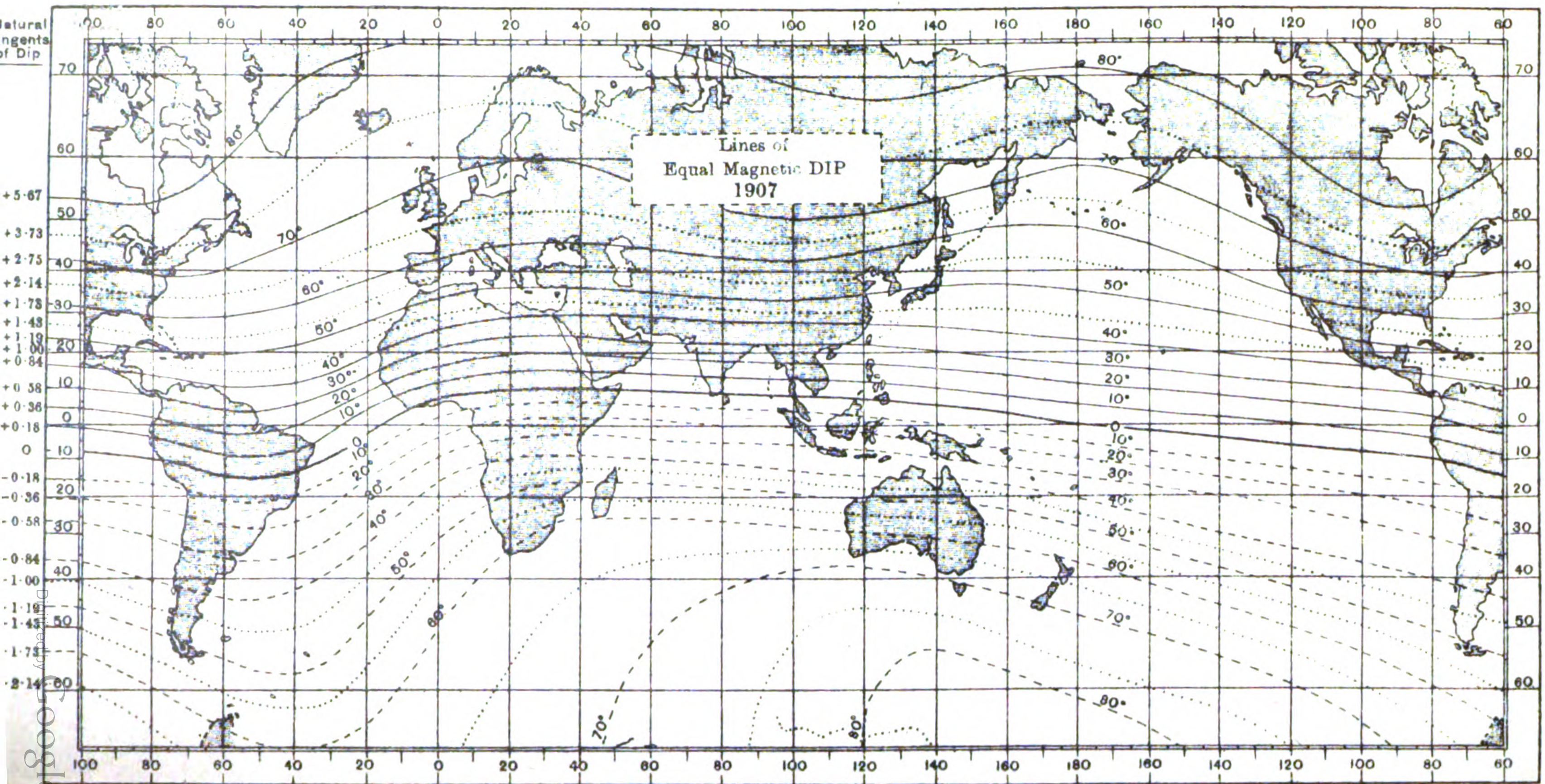
No. 1.

To face p. 610



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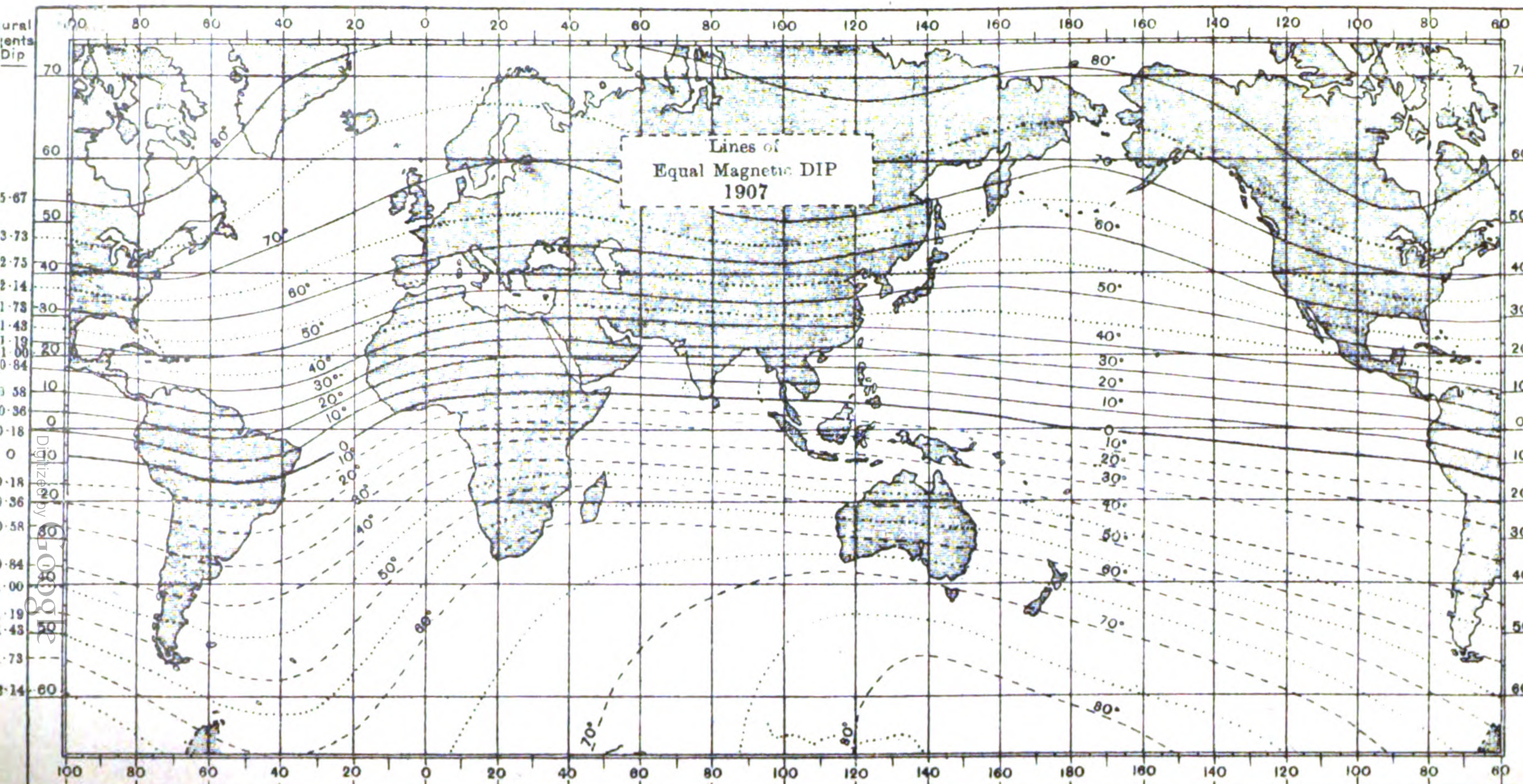

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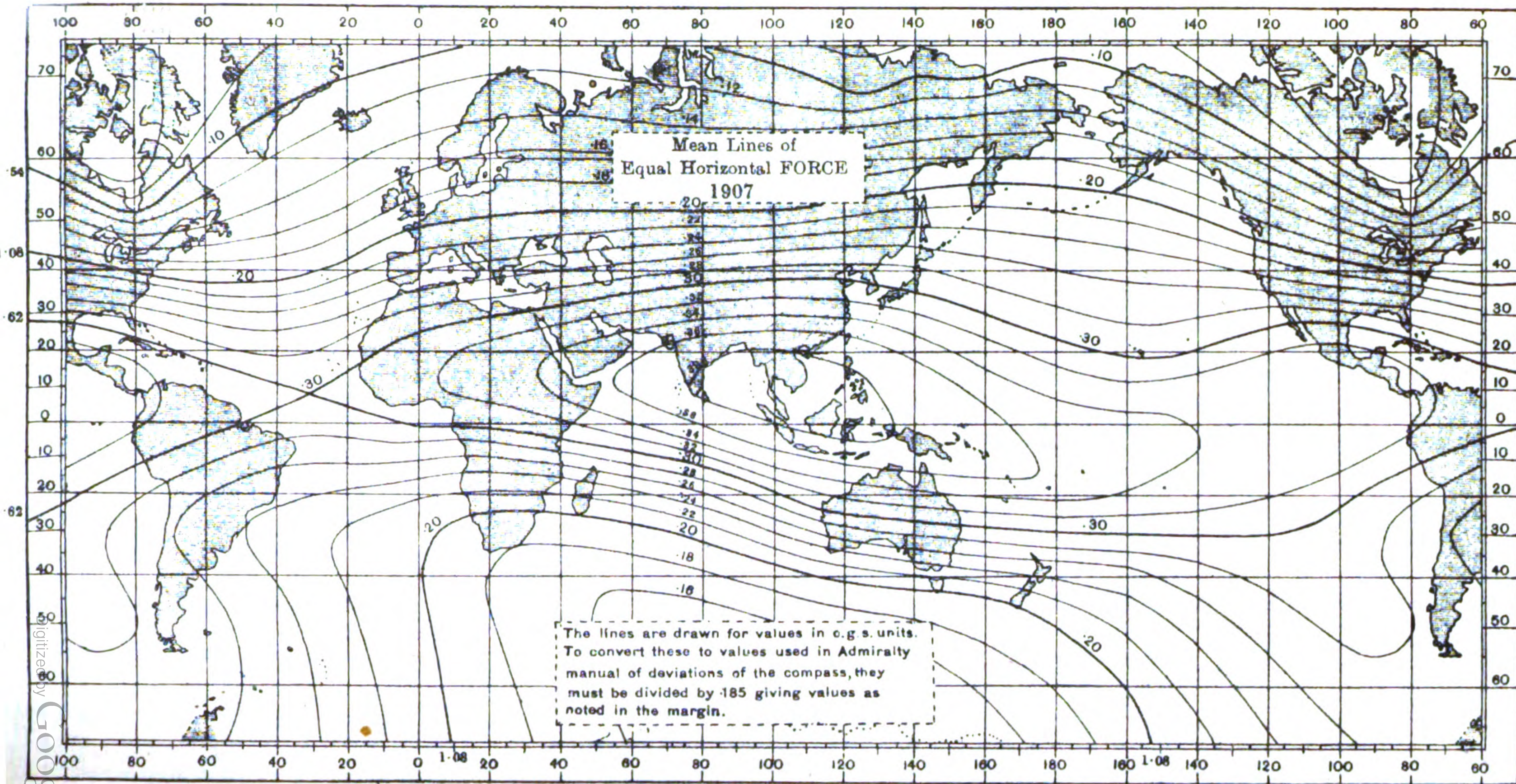

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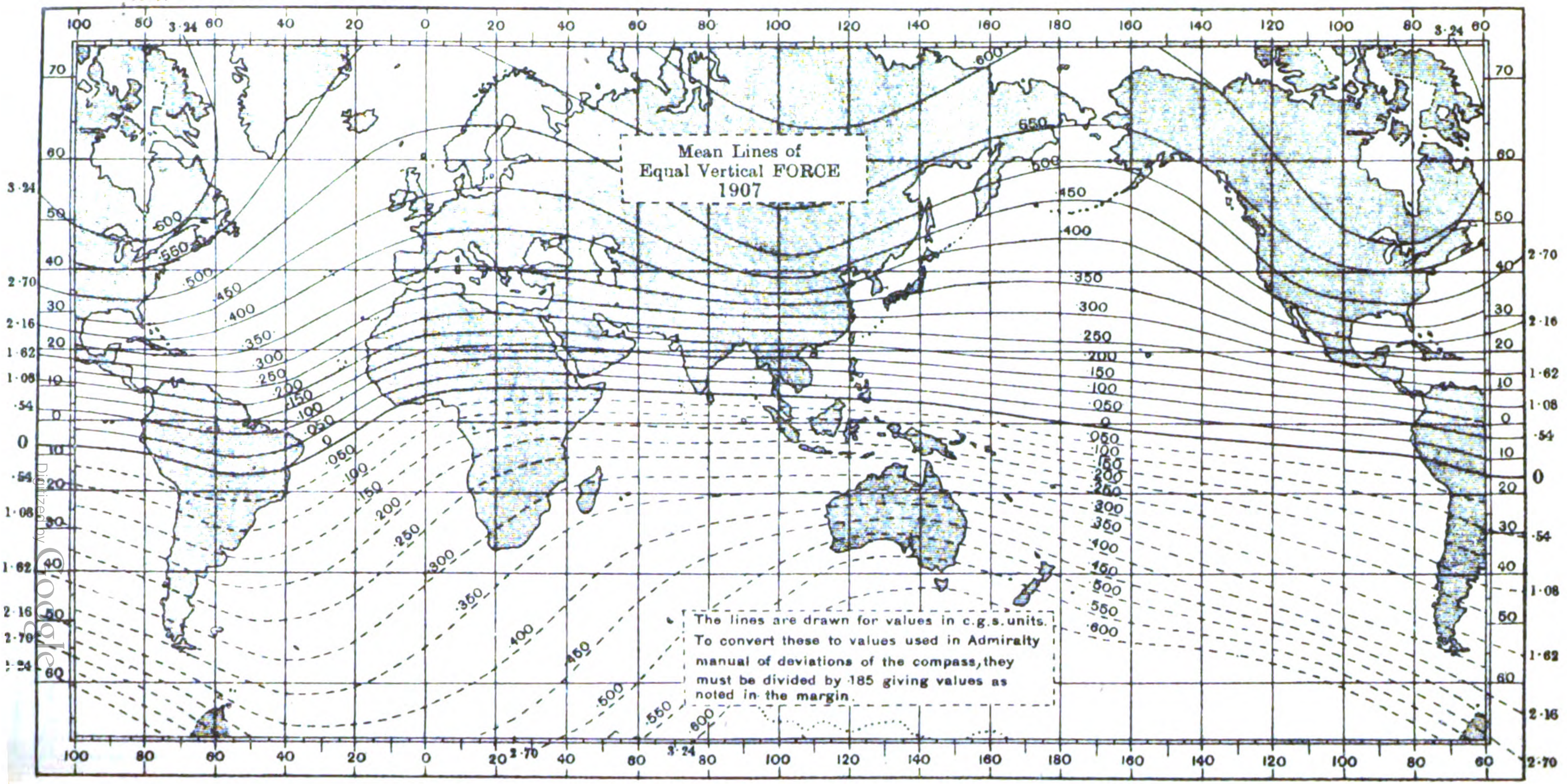

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Nº 4.

scale, when the spirit level indicates that the instrument is perfectly horizontal.* Now, to test the vertical force of the ship on any compass, take your "Dipping-needle" on shore, *in a spot free from Local Attraction,* and adjust it to zero, in the plane of the magnetic meridian; then, returning on board, remove the compass, and put the "Dipping-needle" in its place, bedding it up with wood or otherwise until it is perfectly levelled, and occupies *exactly* the same position and direction the compass needle did. Then, if it be found deflected from zero, it shews the existence of vertical magnetic force *below* the compass, commensurate with the amount of such deflection. This can be compensated by inserting a vertical steel magnet in a suitable receptacle, directly underneath the very centre of the instrument; which magnet is to be slid up or down till the point of the "Dipping-needle" again rests at 0°, when it is to be secured in place, and the compass returned. Generally, it is the red pole of the magnet which requires to be uppermost, but this is very easily seen on trial.

Adjustment of Dipping-needle on shore.

The adjustment for heeling error when carried out as above can only be considered approximate. To get an exact result the vertical magnetic force at the place of the compass on board ought to bear the same ratio to the vertical magnetic force on shore that the horizontal force on board bears to the horizontal force on shore.

Heeling error varies with the latitude.

The horizontal force for a corrected compass on board may usually be assumed as 90 % of the horizontal force on shore, and this proportion may be used when actual measurement of the horizontal force on board has not been made. Therefore, when adjusting the dipping needle on shore it should be set to about 90 % of the then determined vertical force: but an error of 5 % on the vertical force for a ship anywhere near the British Islands gives rise to only 1¼° to 1½° of heeling error for 10° of heel. The accompanying Plates shew respectively the lines of equal Horizontal and Vertical Force, and of equal Magnetic Dip.†

This adjustment may also be performed by comparing the vibrations of the dipping needle in a given number of seconds on shore with the vibrations made in the same number of seconds on board. Whatever number of vibrations may be made on shore, the correcting magnet must be raised or lowered to give 90 % of

Vibrating needle.

* Lord Kelvin has patented a very neat arrangement for determining the vertical force below the compass. See page 220. This he has recently improved by substituting for the sliding paper weight a small bar-magnet moved up and down by a micrometer screw. The vertical component magnetic force of this little magnet is used to balance, and so to measure, the vertical magnetic force exerted on a pair of dipping needles.

† See footnote, page 220.

these vibrations with the dipping needle in the place of the compass on board. The axis of the pivots of the needle should be North and South. The first method is preferable.*

This is a very important adjustment in all ships, but more especially in those whose cargo is largely composed of iron ; and as it is certain that such vessels cannot be heeled every voyage, owing to the unceasing hurry-scurry in mercantile affairs, such a simple and inexpensive mode of effecting it should not be neglected. Unfortunately, this adjustment, as at present effected, only holds good for the Magnetic Latitude in which it is made.

Adjustment of heeling error only good in magnetic latitude in which it was made.

For example, the vertical force below the compass is compounded of Induced as well as Sub-permanent magnetism, therefore the disturbance due to heeling arises from *two distinct causes;* and we have shewn that these require different treatment, inasmuch as the *transient* induced magnetism of soft iron cannot be satisfactorily compensated by *permanent* steel magnets. Moreover, iron which was horizontal with the ship upright, partakes also of the nature of vertical iron when she heels over, which at once introduces a fresh disturbing element. This second portion of the heeling error is lessened by the quadrantal correctors; a consideration of diagrams 14 and 15, in the first of which the ship is shewn upright, and in the second as heeling some 27°, will make this evident.

As already stated, the quadrantal correctors being composed of soft iron, readily become magnetised by induction from the earth's force. In the northern hemisphere, therefore, their upper parts for the time being acquire blue polarity, and the lower red polarity. Please note the words "for the time being."

Effect of Quadrantal correctors.

So long as the ship is upright, these globes are inoperative on North and South courses, but when she heels over, the *lower* part of the corrector on the weather side of the ship is raised approximately to the level of the compass needles, and, having red polarity, helps to neutralise the blue polarity of the weather side of the ship. In this it is assisted by the blue polarity of the *upper* half of the lee corrector. Of course the opposite effect is produced in South magnetic latitudes, and thus the quadrantal correctors accommodate themselves to the varying magnetic character of one portion of the ship's soft iron. Usually it is found in practice that the quadrantal correctors are insufficient to compensate the whole of the heeling error due to the above

* For a full account of experiments with a vibrating needle, used both horizontally and vertically, see Martin's *Lectures on Compass Adjustment*, pp. 70 and 87. Messrs. G. Philip & Son, Ltd.

Diagram No. 14.

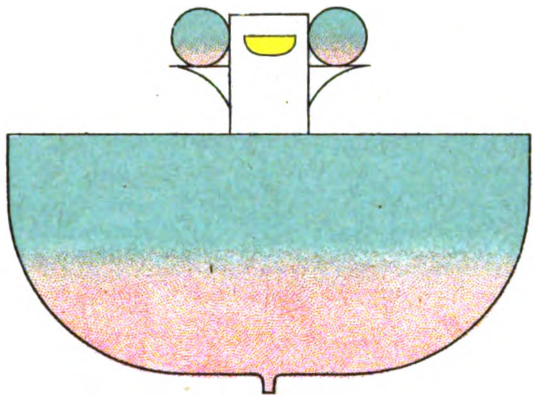

Diagram No. 15.

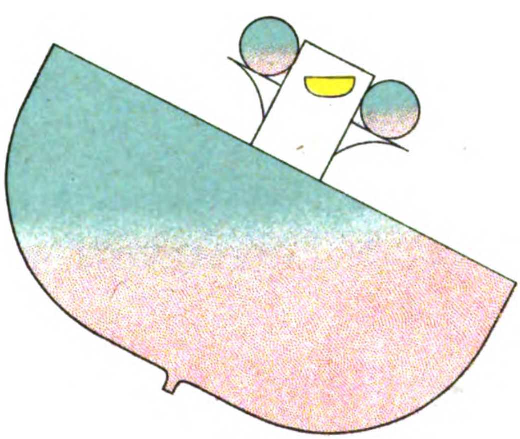

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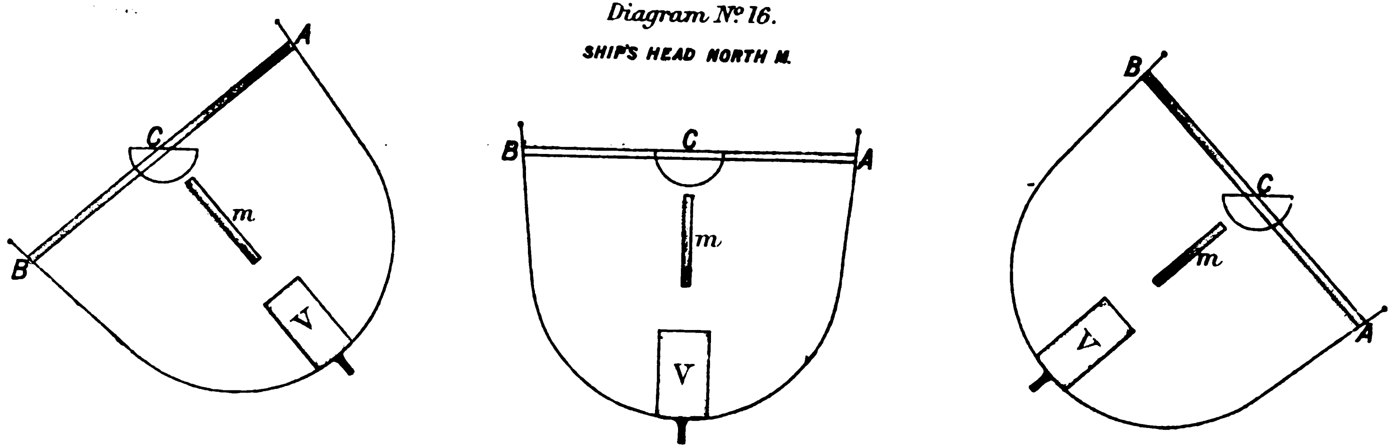
Diagram No. 16.

SHIP'S HEAD NORTH M.



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cause. Another small constituent of the heeling error is corrected by the Flinder's bar.

Taking into consideration the many forces operating on the compass under the influence of heel, their adjustment can only be considered fairly reliable in such *foreign-going* vessels as the Atlantic liners before alluded to—which, in the run from the United Kingdom to New York, are all the time *practically* in the same Magnetic Latitude, the difference not amounting to 3°.

Although the "heeling magnet" is very useful in bringing the heeling error within moderate bounds, the Navigator must constantly be on his guard and avail himself of every opportunity to determine this insidious error, and readjust it by actual *observation at sea.*

Advantages of heeling error compensation.

To see what a great advantage a vessel has whose heeling error is compensated over another where it is not so, just suppose them to be on northerly or southerly courses in a rough beam sea. In the one case, each time the ship rolls, the vertical magnetic force below the compass will come out now on one side of the needle, and now on another, causing the card to be alternately pulled to starboard and port at every roll; and should this pull happen to coincide with the period of vibration due to the motion of the ship, *the swing of the card will be so great as to render it perfectly useless.* In such cases, a man ignorant of the science of compass adjustment will be almost certain to attribute the excessive swing to some inherent fault of the compass, and inwardly curse the maker. On the other hand, the properly compensated compass will remain comparatively steady under all circumstances, and any little swing will be due to purely mechanical causes. In the latter case, the swing may be lessened by affixing deep wings of talc to the under side of the card, on its outer edge. These will help to steady it, by their resistance to the air.

In diagram No. 16, facing this page, let *V* in each of the figures represent the vertical component of the ship's magnetism, and its effect on the compass-needle, when the vessel rolls, will be easily understood. *BA* represent the deck beams, *C* the compass, and *M* the compensating magnet.

It has already been shewn how necessary it is that the semicircular magnetism, causing the deviation on East and West, should be resolved into its constituent parts, and each compensated by the means suitable to it; but to impress it more vividly on the mind, just consider what happens when this has been neglected.

Result of improper compensation

Take the case of a southern-going vessel, having—say 5 points *natural* deviation on East, 3 of which are due to vertical iron. The adjuster, having no time given him to sift the matter, compensates all 5 points, in happy-go-lucky fashion, by means of *permanent steel magnets*, and so the compass is rendered correct *for the time being*. But as the vessel goes south, the vertical iron loses its power over the compass, and on the Magnetic Equator exerts none whatever; the steel magnet, on the contrary, is as strong as before, and having now all its own way—(Happy Magnet!!)—causes an error of three points. By the time the vessel has got off Cape Horn, vertical iron has *again* become strongly magnetic, *but now with reversed poles, so that it pulls in the same direction as the steel magnet, and both acting together, cause* 6 *points of deviation*. Not only is this large error a serious trouble in itself, *but the directive force of the needle is so reduced* as to make the compass sluggish, and almost worthless to steer by.

Some uninformed men in this fix take up the magnets altogether, which certainly may mend matters, but won't cure them. They even eye the magnets themselves as something dangerous, actually throw them overboard, are rather proud of the exploit, and boast of having done so to their nautical chums.

How to keep spare magnets.

If ignorant of the principles of compass adjustment, the more rational plan would be to tie the magnets together in pairs of equal size—the red end of one touching the blue end of the other—and consign them to the forepeak, or the carpenter's storeroom. When so fastened together, they retain their magnetic force unimpaired, while they effectually neutralize each other's action, and so cannot play tricks with a compass *or chronometer*, should they *accidentally* be placed near them. In this way they will be ready for use when next required, and the expense of buying others will be saved.

Advisability of determining natural Deviations before adjusting.

Before adjusting a new vessel, it is advisable to swing her on the eight principal points *by each compass*, and ascertain the Co-efficients, which, when recorded, are afterwards useful in connection with the magnetic history of the ship; but with three or four compasses the process is a tedious one, occupying at least a whole day, irrespective of the time required at the finish for putting down the magnets; and it is only in rare cases, such as yachts, or men-of-war, where time is of less importance, that this would be practicable. *When the natural errors are not too large*, time may be saved and several swingings avoided by the use of Napier's diagram, but extreme cases, which often occur in practice, cannot be treated this way.

Enough has been said to convince anyone that *reliable* compass adjustment is beset with difficulties, and cannot be lightly undertaken. What dependence, then, can be placed on the hurried performance which is daily witnessed in some of our largest ports, when a lot of magnets are slapped down as the vessel leaves the dock gates, and a Deviation Card handed to the Captain worth little more than the paper it is written on? This, however, is seldom or never the Adjuster's fault, but is the result of a vicious system against which conscientious men dare not shew fight, since less scrupulous competitors are ever ready to step in and adjust (?) in half the time, if necessary, and for half the money. Strange to say, anyone with sufficient money or credit to rent a shop can style himself a Compass Adjuster, as no Government test "exam." is required; so, for legal purposes, Tom, Dick, or Harry suit equally well.

Comparative uselessness of Deviation Cards.

In the course of a voyage, many opportunities present themselves for adjusting or forming a Deviation Table, and such chances should be carefully sought for and utilized. The man responsible for the navigation of a metal vessel cannot be too zealous in this respect.

Ports on Magnetic Equator.

The ports of Callao, Bahia, Calabar, Aden, Madras, Colombo, and many others, are practically on the magnetic equator, and ships lie at anchor in them for weeks, during which their captains might perfect the Sub-permanent and Quadrantal portion of the adjustment; and be prepared to complete it, as already explained, on return to high latitudes.

This being satisfactorily accomplished, and the adjustment being in all respects carried out in conformity with the foregoing rules, it is strongly recommended not to fiddle-faddle afterwards with the magnets, in what would only be vain attempts to correct the subsequent comparatively small errors *sure to arise* from time to time. Unless the vessel be new, or has had alterations made affecting the compass, these errors will be due entirely to "Retained" Magnetism, over which, from their "come-and-go" character, it is impossible to exercise any permanent control.

To keep a compass exactly correct at all times and places, the magnets would have to be everlastingly shifted about, than which —it is almost needless to say—nothing could be more injudicious.

The proper way to circumvent the difficulty is to keep a Compass Record in some such form as that given on page 629.

This particular one is kept in stock by the publishers of "Wrinkles."

When the writer was in the service of the P. S. N. Co., and had to touch regularly at a couple or three dozen ports on the round trip, it was his practice to avail himself of the natural marks for swinging ship to be found in many of the harbours. For example, when at anchor in a port like Rio de Janeiro, it is easy to ascertain the magnetic bearing of a distant object, such as a mountain peak, well-defined hill top, or small island, by taking its *true* bearing off the harbour plan with a Field's Parallel Ruler, and applying to it the *corrected* variation. The difference between this and the compass bearing, as the ship swings round to wind or tide, is, of course, the deviation for the particular point on which the ship's head may be at time of observation. This method is independent of the sun, who will not always show himself when wanted, and in the tropics may have too high an altitude to be serviceable; with the additional advantage that, *as the bearing of the object is constant, no calculation is necessary.*

Adjusting by bearing of distant object.

In Rio, the steamers of the P.S.N. Company invariably anchored in those days off the small island of Mocangué, which was their coaling station. From this position, the conspicuous peak of Tijuca (3,316 feet high) bore S. 67½° W. magnetic, distant 9½ miles, and was therefore fairly adapted for this purpose (1895). A remarkable peak in the Organ Mountains, from its greater distance, was a better object, and could be used indifferently with Tijuca, when one or other happened to be shut out by the masts or funnel. This last peak was not laid down on the harbour plan, but its bearing was ascertained in the simplest manner by *merely taking the horizontal sextant angle between it and Tijuca.**

Adjusting marks in Rio de Janeiro.

At this anchorage a couple of excellent *transit* marks were also available for compass work. On the eastern side of the harbour are two forts, viz., Gravata and Santa Cruz. Their western faces were in one on the bearing of S. 3° W. M.; and *in the same line*, and close to the anchorage, is a low-lying rock off the S.W. corner of Mocangué. Variation in 1895, 6½° W.

May have been battered down in recent revolution.

The lighthouse on Raza Island, in transit with this rock, bore S. 8½° W., M. As the ship swings to wind and tide, one or other of these two transit marks is pretty sure to be "on"; but in any case a good eye can always estimate the difference when

* On these occasions, should the angle exceed the limits of your sextant, it can be measured at twice by using some intermediate object lying in the same horizontal plane.

they happen to be a little open of each other. Whether in transit or not, be sure and observe the bearing of the *back* object.

Always observe transit bearing of *back* object.

Should the navigator, however, not be provided with a large scale plan of the harbour, or the sun not be visible, the *mean* of two bearings on East and West *by compass* will give the *mag.* bearing of the distant object. The old advice on this subject was to observe the compass bearing on *every* point as the ship swung round, dividing by 32 to get the required M. bearing; but Towson* has shewn conclusively that the first method is more correct, as well as more convenient. Thus, if with head west, by compass, the observed bearing is S. 81° W., and with head east it is N. 63° W., we have

How to obtain the *Mag.* bearing of an object from its *compass* bearing.

N. 63° W.
N. 99° W.

2) 162°

Mag. bearing of . . N. 81° W. . . . distant object.

Should the sun be visible, there is a very correct mode of finding the required bearing, which can be put into practice whenever there is a true sea horizon. *In a confined harbour this may be obtained from a boat alongside, if the shore line is not nearer than 1½ miles.*

How to obtain Astronomical *true* bearing of distant object.

Measure with the sextant the oblique angular distance between the sun's nearer limb and the object selected, *taking a point at the water-line* (imaginary or otherwise) *vertically under the latter.* At the same instant let another observer take the sun's altitude in the usual way, and note the time. Then, neglecting minor corrections, proceed as follows:—Find the sun's true altitude by Table 38 of Raper. Add 16′ to the observed angular distance, to reduce it to the sun's centre. Next, from the log. Cosine of the distance subtract the log. Cosine of the altitude, and the result will be the log. Cosine of the *horizontal angle* between the sun's centre and the object. Thus:—

Example I.

Corrected angular distance .	76° 40′	. Cosine	.	9·3629
☉'s true altitude	28 10	. Cosine	.	9·9453
Horizontal angle between ☉ and object. } =	74° 50′	. Cosine	.	9·4176

* Page 124 of 1890 Ed.

EXAMPLE II.

Corrected angular distance .	$98^{\circ}\ 20'$	.	Cosine	.	9·1612
☉'s true altitude	30 10	.	Cosine	.	9·9368
	80 21	.	Cosine	.	9·2244
	180				
Horizontal angle = ...	99° 39′ between ☉ and object.				

In the last example the angular distance exceeds 90°, and it is therefore necessary to take the *supplement* of what would otherwise have been the required horizontal angle. The sun's true bearing, at the time the observations were made, having been found, either by the A B C Tables or by the old alt-azimuth problem, apply to it the horizontal angle just obtained, and you get the *true* bearing of the object. To this apply the *corrected* variation at place, and you have the desired *mag.* bearing with even more than the necessary precision. *The three log. cosines make this problem easy to remember.* To ensure an accurate result, the angular distance must be at least double the sun's altitude.

Arica—facilities for Compass Adjustment.

Captains of vessels plying regularly to certain ports might keep a memorandum of the M. bearings of distant peaks, &c., as seen from the anchorage they frequent. Thus at Arica, in Peru, there were several capital marks, as under:—

Morro de Sama	N. 59¼° W., M.	(distant 41 miles).
Notch Peak	N. 13¼° W.	"
Left Peak......................	N. 20¼° E.	"
Right Peak	N. 23½° E.	"
Sajama	N. 53¾° E.	"
Centre of Table Mount ...	N. 80¼° E.	"

These bearings—which, from there being no appreciable annual change in the variation at this part of the coast, will hold good for an indefinite time—were determined at anchor, with the new mole S.E. ½ E. (M.), 3¼ cables distant; but from the great distance of these mountains, the ship might shift her position very considerably without affecting the bearings. Taking the Morro de Sama—one of the nearest—a vessel would have to shift her berth ¾ of a mile *at right angles to its line of direction* before causing an alteration in the bearing of even 1°. Therefore, to adjust compasses, a vessel might steam slowly round the Bay. Here the Pelorus, or Lord Kelvin's Azimuth Mirror, would come in tip-top.

In Plymouth Sound the Admiralty have four mooring buoys just inside the breakwater, any one of which is used to swing men-of-war. On application to the naval authorities, merchant vessels may have the use of the two smaller ones. The following table (Epoch 1906) gives the marks and *true* bearings employed for the purpose. The variation should be taken for the year required, and applied to the *true* bearing to ascertain the *magnetic* bearing for the date required. **Plymouth.**

Buoys.	Eddystone. Dist. 10½ miles.	Kite Hill. Dist. 11 miles.	Sheep's Tor. Dist. 10½ miles.	Tor Hill trees. Dist. 3¾ miles.
	° ′	° ′	° ′	° ′
No. 1 (East).	S. 26 50 W.	N. 28 30 W.	N. 25 40 E.	N. 3 15 E.
„ 2	S. 26 15 W.	N. 27 45 W.	N. 26 10 E.	N. 5 0 E.
„ 3	S. 25 15 W.	N. 27 0 W.	N. 27 10 E.	N. 8 40 E.
„ 4 (West).	S. 24 45 W.	N. 26 5 W.	N. 27 50 E.	N. 11 2 E.

Portland Roads.

Portland Roads afford another good place to swing ship, and buoys are not necessary. The Admiralty large scale plan has lines drawn across it at intervals of 1°, shewing the *True* bearing of Hardy's Monument from *any part* of the anchorage. Consequently a ship, after bringing up, has only to fix her position on the chart by angles or bearings, and forthwith her officers have at their beck and call the True bearing, to the nearest quarter of a degree, of a well-situated distant object.

After applying the Variation reduced to date, the *Magnetic* bearing is ready to hand at all times as the ship swings to wind or tide. This is a really excellent system, and the locality lends itself nicely to it. The bearings range between N. 30° W. and N. 40° W. (true).

Hardy's Monument

Hardy's Monument crowns the summit of Black Down in lat. 50° 41′ 10″ N. and long. 2° 32′ 52″ W. It was erected by the family to the memory of Nelson's flag-captain, and is an octagonal stone tower, 72 feet in height. The diameter at base is 29 feet, and at top is 15 feet. Notwithstanding these substantial dimensions, it looks quite diminutive from Portland Roads, a distance not exceeding nine miles. The top of the tower is 861 feet above mean sea-level, and is a somewhat airy perch in a N.W. gale, as the writer has occasion to know.

As a general rule, when at single anchor in a tideway, the distance of a selected object should not be less than 10 miles; but if the vessel is taut moored, and the observing compass be well forward, five miles will suffice.

Observations unreliable when ship swings rapidly.

When swinging pretty fast, with wind and tide in the same direction, the observations will not be nearly so reliable, owing to friction causing a heavy card to drag with the ship, in opposition to the directive force of the needle. A light card, like Lord Kelvin's, has a great advantage in this respect, as friction on the bearing point is reduced to a minimum. To counteract the dragging tendency, keep quietly moving the compass in the gimbals as the ship goes round.

River Mersey, Vauxhall Chimney.

In the Mersey, ships may determine their deviations by the bearing of Vauxhall chimney, in transit with any one of a system of figures painted in large characters on the dock walls and sheds. These figures now give the *true* bearing of the chimney, reckoning from north towards south by the east. Thus 110° would be read as N. 110° E., or S. 70° E. Variation 18½° W. in 1906.

Similar facilities are also given at Kronstadt. Capt. J. Belavenetz, of the Russian Imperial Navy, has made the following arrangement in the commercial port of Kronstadt to enable mariners to determine the deviations of their compasses, as resulting from the effects of the iron of the ship, or the cargo on board, whilst lying at anchor in the great roadstead of that port: viz.—

Kronstadt.

The *true* bearings of the foundry chimney from various parts of the western wall of the commercial port of Kronstadt are indicated by a series of marks, ranging between the bearings of N. 89° E. and S. 79° E., painted on the western face of the wall.

The degrees are marked in figures legible from the roadstead of Kronstadt, the even figures being on a black ground, and the odd figures on a red ground, in the following order, indicating as here stated, under each figure,—

9	80	1	2	3	4	5	6	7
S.79°E.	S.80°E.	S.81°E.	S.82°E.	S.83°E.	S.84°E.	S.85°E.	S.86°E.	S.87°E.

8	9	90	9
S.88°E.	S.89°E.	East.	N.89°E.

There is quite a similar arrangement at Cherbourg, and to facilitate adjusting, there are eight warping buoys in a circle, with one in the centre.

Deviation of wooden vessels marked on Compass Card.

In the absence of cargoes containing iron, *wooden* vessels going short voyages have their deviation nearly constant, in which case it is not a bad plan to write it neatly on each point of the compass card for ready reference. Do not, however, *when correcting a bearing*, commit the blunder *of taking the deviation from the bearing point*. It must, of course, be taken from the one which corresponds to the direction of the *ship's head* at time of observation. *This mistake has frequently been made.*

Leaving Liverpool in winter, it often happens on the approach of a southerly gale that the atmosphere is more than ordinarily clear, although the sky may be quite overcast. At these periods it is possible to see almost fabulous distances; and in the absence of the sun—a rare visitor in winter—transit-bearings of lighthouses, mountains, and other shore marks, can be used to give the deviation with all needful accuracy. *Then comes one of the advantages of having large scale Admiralty Coast Sheets, from which to get the true bearings.*

Transit-bearings of shore marks

For example, about 7 miles after passing the North-West lightship, Great Orme Head lighthouse (readily distinguished with the binocular) will be seen in one with the conspicuous peak of Penmaen Mawr. Six miles further on, the latter comes in transit with a lofty mountain named Carnedd Llewelyn. But Carnedd Llewelyn, from this point of view, is not readily picked out by a stranger. Again, the bearing of the Skerries and South Stack lights, when in one, happens by good fortune to coincide with the fairway course down the Irish Channel, passing within nice range of Bardsey and the Smalls; so that, if when in transit they are brought right ahead for a couple of minutes or so, these lights will prove additionally an invaluable guide. Of course, by taking their transit-bearing in the ordinary way when passing, the deviation will be found for any point on which the ship's head may happen to be at the moment.

How to name the Deviation.

In *naming* deviation ascertained in this manner, recollect that if the *shore bearing* is to the right of the *compass bearing*, the deviation is easterly, and *vice versâ.*

Now, in regard to transit-bearings, there is a point to be noted. The further off the back object is, so much the better, for then the bearing is "tender," and the exact moment of transit is easily noted. On the other hand, when the objects lie tolerably close together, and the observer some little distance from them, it is difficult to discover when they are actually in one, and an error of 2° or 3° in consequence is quite possible.

Furthermore, when observing, be sure to take the compass bearing of the *back object*, which shifts but slowly, and note the reading at the instant the other object is seen to transit. The more rapid change in the bearing of the *near object* renders it difficult to follow and get correctly at the proper moment. Sometimes, when *one* of the objects is indistinct, an assistant with a binocular to tell you when the objects are exactly "on" is a great help.

There are literally thousands of suitable marks all round our coasts; and a few are now given, which will be found convenient, especially by vessels navigating the George's, Bristol, or English Channels. Those marked thus * are only available in fine clear weather.

		°		
Turret on pier and New Brighton church spire (River Mersey)	S.	87	W.	–
Rock lighthouse and New Brighton church spire	S.	33½	W.	–
Great Orme Head lighthouse and Penmaen Mawr	S.	49¾	W.	–
*Penmaen Mawr and Carnedd Llewelyn	S.	27½	W.	–
*Penmaen Mawr and Y Foel Fras	S.	21½	W.	–
Tower on Puffin Island and Penmaen Mawr	S.	17	E.	+
*Moelfra Island and Snowdon	S.	2½	W.	–
*Beacon on Dulas Rocks and Snowdon	S.	1¼	W.	–
*Point Lynas lighthouse and Snowdon	South			+
Point Lynas lighthouse and Penmaen Mawr	S.	32½	E.	+
*Middle Mouse and Snowdon	S.	10½	E.	+
Middle Mouse and Point Lynas lighthouse	S.	58¼	E.	+
Beacon on West Mouse and Coal Rock shore marks—three in one	S.	38	W.	–
*Beacon on West Mouse and Snowdon	S.	19¾	E.	+
*Mount Pengarn and Snowdon	S.	21¼	E.	+
Skerries and South Stack lighthouses	S.	45¼	W.	–
Skerries lighthouse and Pen Gybi (Holyhead Mountain)	S.	40¼	W.	–
*Skerries lighthouse and Snowdon	S.	22¼	E.	+
Skerries lighthouse and Mount Pengarn	S.	31½	E.	+
*Holyhead Breakwater lighthouse and Snowdon	S.	31¼	E.	+
*Pen Gybi (Holyhead Mountain) and Snowdon	S.	35¾	E.	+
*South Stack lighthouse and Snowdon	S.	37¾	E.	+
*Pen Gybi (Holyhead Mountain) and Carnedd Llewelyn	S.	49¾	E.	+
*South Stack lighthouse and Carnedd Llewelyn	S.	51¼	E.	+
Left xme of North Stack touching Breakwater lighthouse	S.	82	E.	+
*Mynydd Mawr and Snowdon	S.	69¼	E.	+
*Wicklow Head lighthouse and Lugnaquilla Mountain	N.	69¾	W.	+
*Wicklow Head lighthouse and Thonagee	N.	49½	W.	+
*Wicklow Head lighthouse and Great Sugar Loaf	N.	6½	W.	+
Wicklow Head lighthouse and Little Sugar Loaf	N.	1¾	E.	–
*Slieve Boy and Mount Leinster	N.	81¾	W.	+
*Arklow Rock and Crogan Hill	N.	56½	W.	+
*Tara Hill and Crogan Hill	N.	14	W.	+
Tuskar lighthouse, Greenore windmill, and Fourth Mountain	N.	42½	W.	+
*Coningmore Rock and Slieve Coiltia	N.	17	W.	+
*Hook lighthouse (Waterford) and Tory Hill	N.	7¾	W.	+
*Tory Hill, seen between Brownstown Head towers	N.	17¼	E.	–
*Metal-man tower (Great Newton Head) and Tory Hill	N.	28	E.	–
*Minehead lighthouse and Knockmealdown Mountain	N.	19½	W.	+
*Capel Island tower and Knockmealdown Mountain	N.	15	E.	–
*Ballycotton lighthouse and Knockmealdown Mountain	N.	27	E.	–
Right face of Dognose (Queenstown) and Roche Pt. lighthouse	S.	6	W	–
Left xmes of Weaver Point (known by its signal station) and Cork Head	S.	38¼	W.	–

Reanie's Head and Little Sovereign		S. 82 W.	−
Reanie's Head and Big Sovereign		S. 80½ W.	−
Fastnet lighthouse and Mizen Peak		N. 37¾ W.	+
*Fastnet lighthouse and Hungry Hill		N. 0½ E.	−
Man-of-War Sound white beacon, and Leamcon Tower		N. 21 E.	−
Fastnet lighthouse, and Leamcon tower open left of white beacon		N. 21¼ E.	−
*Left xme of Sheep Head and Hungry Hill		N. 37½ E.	−
Calf Rock lighthouse and summit of Skariff Island		N. 19¾ E.	−
The Cow and summit of Skariff Island		N. 26¾ E.	−
The Bull and summit of Skariff Island		N. 33¾ E.	−
North Bishop Rock and Ramsay Hill		S. 11½ E.	+
North Bishop Rock and Llaeithty Peak		S. 71¾ E.	+
Carreg Rhoson and Llaeithty Peak		S. 88¾ E.	+
Right xme of St. David's Head and Ramsay Hill		S. 47¼ W.	−
South Bishop lighthouse and Ramsay Hill		S. 82¼ E.	+
South Bishop lighthouse and Llaeithty Peak		N. 76¾ E.	−
South Bishop lighthouse and left xme of St. David's Head		N. 71 E.	−
South Bishop lighthouse and North Bishop Rock		N. 37¾ E.	−
Smalls lighthouse and Grassholme Island (highest part)		S. 74 E.	+
Smalls and S. Bishop lighthouses and xme of St. David's Head		N. 71 E.	−
Grassholme Island and S. Bishop lighthouse		N. 39¼ E.	−
South-West xmes of Skokham Island and St. Ann's Head		S. 59¾ E.	+
Great Castle Head range lights (Milford Haven)		N. 58¼ E.	−
St. Ann's Head range lights		N. 24 W.	+
Wolf and Longships lighthouses		N. 36¼ E.	−
Lizard lights		S. 82½ E.	+
Killiganoon House and Penarrow Point (Falmouth)		N. 1¾ W.	+
Eddystone lighthouse, and chapel crowning Rame Head		N. 30 E.	−
" " and Picklecombe Fort		N. 39 E.	−
" " and Rifle Butt on Staddon Heights		N. 48¼ E.	−
South Foreland lights		N. 84½ W.	+
Ushant lights, in one		S. 89¼ E.	+
Les Pierres Noires, and Pte. St. Mathieu		S. 82¾ E.	+
" " " and Kermorvan		N. 77½ E.	−
Tevennec and Ar Men Rk.	The Saints lights.	N. 81 W.	+
Ar Men Rk. and La Vieille	The Saints lights.	S. 68¾ E.	+
" " " and Isle de Sein	The Saints lights.	S. 67¾ E.	+
Tevennec and Isle de Sein	The Saints lights.	S. 78 W.	−
La Vieille and Tevennec	The Saints lights.	N. 23 W.	+

These bearings are all *magnetic*, and adapted to the year 1895. To adapt them to subsequent years, those in the N.E. and S.W. quadrants must be diminished, and those in the N.W. and S.E. quadrants increased, at the rate of 8′ per annum, or a degree in seven years. To facilitate the application of this correction, the proper sign has been placed after each bearing.* The intelligent man will understand that these bearings may be in error as much as ½°, as the *exact* amount of variation depends upon the *exact* position of the observer. The variation, as applied in these pages, is that of the average offing for passing vessels. Further, the distortion of the chart in printing (see page 105) will probably cause a slight error, but the maximum from all causes will seldom or never amount to 1°; the average may be taken at half this. Failing azimuths of sun, moon, or stars, transit bearings are the next best thing. **Limit of error**

It may happen, however, when sailing along shore, that a dis-

* In 1902 the correction was just 1°.

Adjustment by bearing of one distant object.

tant conspicuous object presents itself which is laid down on the chart, but has nothing suitable to transit with it, in which case the Station Pointer comes in *very* handy. Select, in accordance with the rules laid down in the chapter on this instrument, three known and well-defined objects, and at the same instant that the ship's place is fixed by the horizontal sextant-angles between them, let a third observer take the compass-bearing of the distant object, which may or may not be one of those already in use. Then lay off the ship's place on the chart with the Station Pointer, and, using Field's Parallel Ruler or the horn protractor, find therefrom the *true* bearing of the distant object. To this apply, as usual, the Variation at place *reduced for annual change*, which will give its *magnetic* bearing, in readiness to be compared with the observed *compass* bearing.

If the object chosen is a very distant one—say Snowden in Wales, Sca Fell in Cumberland, Snae Fell in the Isle of Man, or Slieve Donard in the Co. Down (all visible from the Irish Channel)—a steamer may be slowed down and steamed half round, so as to get the Deviation on every second point in that semicircle of the compass she would be most likely to use during the next few days. The half hour thus spent will not only conduce to the ship's safety generally, but may, if thick weather comes on, save many a half-hour's groping about.

Crowded out.

For new vessels requiring their compasses adjusted, or ships lying wind-bound in Belfast Lough during overcast weather, the following transit bearings observed by the writer will be found of service. The *true* bearings, in most instances, were determined by Theodolite and sun, and converted into *mag.* bearings for the year 1895, by applying the variation taken from the Admiralty Magnetic Chart of the World. The marks here given are very conspicuous, but to pick them out a stranger would, in most cases, require the assistance of some one locally acquainted. Besides this, the growth of population often causes buildings, once quite solitary, to be so hemmed in by bricks and mortar as to render their identity difficult, if not impossible, from the required point of view. Of course, such marks are only auxiliaries to azimuths of sun, moon, and stars, which for many reasons should always be preferred.

HOLYWOOD HILL HOUSE, in one with

Power's House on Kinnegar and Bellevue, the three houses in one	S. $42\frac{3}{4}^\circ$ E.	+
Holywood Episcopal Church Spire	S. $1\frac{1}{4}$ W.	–
Tudor Hall (centre)	S. $13\frac{3}{4}$ W.	–

No. 1 Pile Lighthouse, in one with

Albert Clock Tower (Belfast)	S.	58½°	W.	−
Gray's House (Hazelbank)	N.	80	W.	+

Grey Point (xme), in one with

Copeland Lighthouse (Mew I.)	S.	79°	E.	+
Glenghana House	S.	63	E.	+
Mrs. Connor's Turret (flag-pole)	S.	57	E.	+
Foster Connor's House (Seacourt)	S.	52¾	E.	+
Tower of Carnalea House	S.	34¼	E.	+
Mount Divis	S.	88½	W.	−
McArt's Fort (Cavehill)	N.	83¾	W.	+

Carrickfergus Castle, in one with

Carnbilly Summit (Cairn)	N.	32°	W.	+
Carrick Church Spire	N.	17½	W.	+
Burleigh Hill House	N.	7¾	W.	+

Helen's Tower,* in one with

Craigdarrah House	S.	19¼°	E.	+
Clandeboye Coast Guard Station	S.	16	E.	+
Rockfield Cottage	S.	12¾	E.	+
Cramsie's Villa (turret)	S.	11½	E.	+
Clandeboye Railway Station (turret)	S.	11	E.	+
Pattison's House	S.	9	E.	+
Centre of Helen's Bay Quarry	S.	3¼	E.	+
Crawfordsburn House	S.	1	E.	+
McNeill's Square Villa	S.	10¼	W.	−
Carnalea House (tower)	S.	13½	W.	−
Ruin in Smelt Mill Bay	S.	23½	W.	−
Foster Connor's House (Seacourt)	S.	29¾	W.	−
Cochrane's House	S.	30½	W.	−
Cochrane's New Villas	S.	31½	W.	−
Bangor Church Spire	S.	39¾	W.	−
Presbyterian Church Steeple	S.	42¼	W.	−
Bangor Castle (turret)	S.	44½	W.	−
Mrs. Connor's Turret (flag-pole)	S.	45	W.	−
Ulster Royal Yacht Club House	S.	45¼	W.	−
Stewart's House	S.	47	W.	−
Islet Hill Farm House	S.	56	W.	−
Ballyholme Windmill	S.	58	W.	−
Groomsport Presbyterian Church	S.	60¾	W.	−
Groomsport Irish Church	S.	62½	W.	−
Maxwell's House, Groomsport	S.	63¾	W.	−
Orlock Point Coast Guard Station	S.	72	W.	−
Copeland Lighthouse (Mew I.)	S.	74½	W.	−
Donaghadee Church	N.	81½	W.	+
Killeghy Spire	N.	65½	W.	+
Mill Isle Windmill	N.	59¼	W.	+
Carrowdore Church	N.	46	W.	+

* Helen's Tower—crowning a hill in the background—about 2½ miles S.W. of Bangor, is quite unmistakable, as is also Scrabo Monument, which lies about an equal distance further off, in the same direction.

SCRABO MONUMENT, in one with

Carnalea House (tower)	S. 25¾° W.	−
Cochrane's House	S. 33¾ W.	−
Helen's Tower	S. 36¼ W.	−
Bangor Church Spire	S. 37¼ W.	−
Ballyholme Windmill	S. 48 W.	−
Islet Hill Farmhouse	S. 48¼ W.	−
Groomsport Irish Church	S. 52½ W.	−
Copeland Lighthouse (Mew I.)	S. 65½ W.	−
Donaghadee Lighthouse	S. 79¼ W.	−
Killeghy Spire	S. 84½ W.	−
Mill Isle Windmill	N. 86½ W.	+
Carrowdore Church	N. 71 W.	+

BALLYHOLME WINDMILL, in one with

Foster Connor's House (Seacourt)	S. 55° E.	+
Mrs. Connor's Turret (flag-pole)	S. 38½ E.	+
Ulster Royal Yacht Club House (flag-pole)	S. 31¼ E.	+
Stewart's House	S. 25¾ E.	+
Ladies' Bathing Hut	S. 18 E.	+
Groomsport Presbyterian Church	S. 67¾ W.	−
Groomsport Irish Church	S. 73 W.	−
Maxwell's House (Groomsport)	S. 76 W.	−
Copeland Lighthouse (Mew I.)	S. 84½ W.	−

PRESBYTERIAN CHURCH STEEPLE,* in one with

Cochrane's House	S. 39° E.	+
Foster Connor's House (Seacourt)	S. 26½ E.	+
Copeland Lighthouse (Mew I.)	S. 87¾ W.	−

BANGOR CHURCH SPIRE, in one with

Ruin in Smelt Mill Bay	S. 23° E.	+
Cochrane's House	S. 3¼ E.	+
Foster Connor's House (Seacourt)	S. 1 W.	−
Sea View House (Ritchie's)	S. 6¾ W.	−
Presbyterian Church Steeple	S. 56½ W.	−
Ulster Royal Yacht Club Flag-pole	S. 56¾ W.	−
Stewart's House	S. 61½ W.	−
Ballyholme Windmill	N. 87¾ W.	+

NOTE.—The variation in Belfast Lough in 1895 was 20½°, and decreases about 1° in seven years.

Not many years ago the water approach from the outer pile lighthouse (locally known as "Jack-in-the-box") to the quays of Belfast was both winding and shallow, but the Harbour Commissioners have remedied this by dredging a new and perfectly straight passage named the Victoria Channel. Between the N.E. end of the Twin Islands and the outer extreme of the Victoria

* There were then but two churches with spires in Bangor, and the Presbyterian one was the nearer of the two.

Channel, the magnetic course was N. $56\frac{1}{2}°$ E. in one direction, and S. $56\frac{1}{2}°$ W. in the other (1895), or as nearly as possible N.E. by E. and S.W. by W. for a good three miles. Here, then, is an excellent opportunity, while going "slow," for testing all compasses by whistle on these two courses. At Grey Point, and further westward, there are measured mile marks, which transit when bearing S. $15\frac{1}{4}°$ W. (M.). The running course between them is therefore S. $74\frac{3}{4}°$ E. and N. $74\frac{3}{4}°$ W. (M.).

One sometimes hears wonderful stories of compasses suddenly "jumping a point or two," without actual alteration of the ship's head, and this is attributed to all sorts of fantastic causes, such as attraction of the land, and so forth. Some even go so far as to say that in the Red Sea, the sun beating fiercely on one side of the vessel in the morning, and on the other in the afternoon, will cause a change in the Deviation of several degrees. Very careful experiments made in that locality by the writer, have satisfied him on the impossibility of this latter supposition; and consequently, if the A.M. and P.M. azimuths disagree, or whenever these perplexing alterations take place, they will doubtless be due to some cause within the ship herself—such as *change of heel*, errors of centreing, bent shadow-pins, loose iron placed in the 'tween decks or anywhere near the compass, boats' davits turned in that had previously been swung out, or some other simple but overlooked cause. Captain S. Mars, however, of the Dutch Meteorological Institute, was able to prove the effect of sunshine on compass error. The maximum difference he observed was $1°{\cdot}7$. On board the French warship *Magellan*, he says that a difference of $3°{\cdot}5$ was noted; and $2°$ on the Dutch steamer *Djocja*. All these instances were in the Red Sea.*

Compasses unaccountably "jumping" a point or two.

Supposed causes

Probable causes.

It is quite common in wheelhouses to find lockers close on each side of the compass, which are nominally for flags only, but in reality soon become stowholes for quartermaster's gear. Have them taken down as quickly as possible.

Wheelhouse Lockers.

An amusing little *brochure*,* by Capt. W. M. Walters, contains the following instructive anecdote:—"There was a steamer lost some little time back in channel during thick weather. It was afterwards discovered that the man who was at the wheel at the time the observation was made, by which the fatal course was fixed, had on one of those magnetic belts which Jack is fond of wearing, in the hope that they will repair the ravages made in his constitution by the sprees of a lifetime. It was supposed that the error observed included the error caused by Jack's

Magnetic belts.

* "Der Schiffskompass und der Schiffsmagnetismus," von S. Mars. Batavia: G. Kolff & Co.

'soul-and-body-lashing' (technical term), which disappeared when he left the wheel, and so led the ship to destruction."

Compare Standard and Steering Compasses frequently.

The course should not be set or kept by the *Steering* compass, and frequent comparisons should be made between it and the *Standard* compass. This last is a most important duty of the officer of the watch. It is seldom that the Steering compass is so well situated for adjustment purposes as the Standard, and consequently it is more liable to change,—notably when a shift of wind causes a shift in the direction of the heel. It is not uncommon when the course is changed—say a point—for an ignorant or thoughtless officer to make the change by the *Steering* compass. For example, if the course by Steering compass should be S.W., he will tell the helmsman to keep her S.W. by S. or S.W. by W., as the case may be. This is entirely wrong. The course should be altered the desired amount by *Standard*, and a signal made to the helmsman when she is exactly on it. The other is a lazy plan, and altogether a bad system. The ship's course is directed by the *Standard* and nothing else; the helmsman steers by *his* compass whatever course *may correspond to it for the time being*. The interval between comparisons depends upon circumstances, but it should never exceed half-an-hour on any one course. So recently as 1915 the Board of Trade issued a notice that steel rings, sometimes used as spreaders inside officers' caps, become magnetised; so that, when worn by an officer taking compass bearings, such rings are liable to cause considerable deviation and render the observations unreliable.

Deviation Cards unreliable.

Because *Deviation-Cards* are condemned in these pages, it is not to be understood that a properly kept *Compass-Record* is worthless: on the contrary, the commander of every iron vessel should keep a daily account of the behaviour of his compasses. In regular Lines it will be found that the compasses of vessels that have already made several voyages on the one route, under similar circumstances will shew time after time pretty nearly the same deviations in the same localities. This, however, should not lead to neglect in observing azimuths, as nothing but constant watchfulness can ensure safety.

Useful form of Compass-Record.

A form of Compass-Record is here inserted, which those who try it will be sure to like. One need only run the eye down the deviation columns to see at a glance the action of each compass during any given period. Some men, on the contrary, set *deviation* altogether on one side, and to correct their courses take the difference between the *true* and *compass* bearing. This

'Total Error.'

"Total error," as it is called, they also enter in their compass book, which is both meaningless and inconvenient. For "Total error," being compounded of *Variation* and deviation, must

Register of Deviations and Daily Comparison of Compasses on board the Steamship "British Crown," from Liverpool to Philadelphia.

Voyage No. 9. Date. 1880.			Ship's Position		Variation by Chart (corrected to date).	Ship's Head Mag.	Ship's Head by			Heel.	Deviations of			Body Observed.	Remarks.
			Lat.	Long.			Standard Compass.	Bridge Compass.	After Compass.		Standard Comp's.	Bridge Compass.	After Compass.		
♄	September	4	41½°	49¾°	−25°	N.71¼°W.	N.70°W.	N.72° W.	N.70° W.	5° S.	−1¼°	+0¾°	−1¼°	✱ Jupiter. ✱ Saturn.	Most excellent obs. and compars.
⊙	"	5	41¼	54¼	−22½	N.69 W.	N.70W.	N.72 W.	N.69 W.	7 S.	+1	+3	None.	⊙	Good obs. & compars.
☾	"	6	41	58	−21	N.72¼W.	N.74W.	N.75½W.	N.72 W.	None.	+1¾	+3¼	−0¼	⊙	Excellent "
♂	"	7	41	64	−16	N.74¼W.	N.76W.	N.76 W.	N.72½W.	1 S.	+1¾	+1¾	−1¾	✱ Capella ✱ Arcturus	" "

NOTE.—This form is just ⅝ the original size.
The entries under Ship's Head Mag. should always be made in red ink.

necessarily be a *constantly changing quantity ;* and, therefore, a record of it is of no value until it has undergone a troublesome sifting process, which would better have been done in the first instance.

There are two modes of determining the Deviation from an azimuth. One is used by Towson in his examples, but the writer much prefers the other, as tending to practise the navigator in the every-day application of Variation and Deviation to the true courses he may wish to steer.

1ST MODE.	°	2ND MODE.	°
☉'s true bearing	S. 57 W.	☉'s true bearing	S. 57 W.
☉'s compass bearing . . .	S. 84 W.	Variation per chart	22 Wly.
Correction, or total error . .	27 Wly.	☉'s *magnetic* bearing	S. 79 W.
Variation per chart	22 Wly.	☉'s *compass* bearing	S. 84 W.
Deviation	5° Wly.	Deviation	5° Wly.

Modes of finding Deviation from an Azimuth.

The number of figures is the same in each case, but in the first mode an unnecessarily new process is originated; whereas, in the mode advocated, the navigator is familiar with the term "Magnetic," with the rule for naming the Deviation according as the *compass bearing* is to the right or left of the *magnetic bearing*, and has not to tax his memory with any fresh formula, this being very similar to the way he would set about turning a *true* course into one by *compass*. Thus:—

	°
True course - - - - - - -	S. 57 W.
Variation per chart - - - - -	22 Westerly.
Magnetic course - - - - - -	S. 79 W.
Deviation - - - - - - - -	5 Westerly.
Compass course to steer - - - -	S. 84° W.

Explanation of Compass Record.

In the Compass-Record suggested, after the date, &c., the comparisons are first jotted down; next the ship's head mag. is entered in *red ink* by way of distinction, this important direction being got by applying the ascertained Deviation to the compass by which it was ascertained—generally the Standard. The Deviations of the remaining compasses are arrived at by simply taking the difference between the ship's head M. and the ship's head as shewn by each compass. The left-hand pages are left blank for remarks, &c.

Masters of vessels seldom have to cope with the perplexities of correcting *un*compensated compasses: it is nearly always done in the first instance by the shore professional, and the subsequent doctoring may or may not be undertaken by the master. At an earlier period in the history of iron vessels, those in command seldom ventured to touch the correcting magnets—magnetism was then an inscrutable mystery; but improved compasses (Lord Kelvin led off), improved facilities for their adjustment (Lord Kelvin again), and the diffusion of compass literature, have all contributed to bring about a better state of affairs.

In the resolution of the many magnetic forces operating upon the compasses of an iron vessel, the now well-known formulæ of the late Archibald Smith have been universally adopted. The mathematical investigations are to be found in the *Admiralty Manual for ascertaining and applying the Deviations of the Compass*, being the joint production of Mr. Smith and the late Captain Sir Frederick Evans, R.N.: but the reading is altogether too stiff for any but learned professors. **Arch. Smith's formulæ.**

When this exhaustive analysis is rendered down and put into practical shape, we get certain short and simple deductions which, with a little study, are well within the reach of those who choose to make an effort. *Nothing* is accomplished without effort of some kind. It mostly requires an effort to turn out at 8 bells to keep the morning watch, *even* with all the delights of a tropical sunrise to look forward to.

In compass work, letters of the alphabet are employed to indicate the magnetic forces of the ship, and these letters go by the name of "Co-efficients." The five principal are represented by **A**, **B**, **C**, **D**, and **E**.

Co-efficient A.

A represents a *constant* effect which does not vary either in name or amount, no matter what may be the direction of the ship's head. It may be regarded as a sort of compass Index-Error, and is due to one or other of several causes, such as errors of observation, want of symmetry in the disposition of neighbouring masses of iron, needles not being truly parallel to the North and South line of the card, incorrect estimate of the Variation, a slightly misplaced Lubber-line, or to what is sometimes called "Gaussin error."

Though **A** is mentioned as *constant*, it is no more so than the index-error of the sextant—indeed, not so much, for a repetition of the swinging process might, and probably would, develop a somewhat different **A** to that first obtained.

A is usually small, and neglected in consequence; + **A** *always* gives Easterly, and – **A** Westerly deviation.

Co-efficient B

Co-efficient **B** indicates *semicircular* deviation, and is a maximum with ship's head on East and West *by compass*. It consequently represents a pull of the needle towards the bow or stern. + B means a pull towards the bow, and − B a pull towards the stern. Thus, with ship's head East by compass, + B would give Easterly deviation, but with head in opposite direction it would cause Westerly deviation. − B has, of course, the reverse effect. This co-efficient may be due to the sub-permanent magnetic character born with the ship, and/or to the inductive magnetism of vertical iron preponderating at one end. B disappears on North and South by compass.

Co-efficient C. Co-efficient C also indicates *semicircular* deviation, and attains a maximum with ship's head on North and South by *compass*. It consequently represents a pull of the needle to starboard or port according as the sign is + or −. Thus, with head North by compass, + C would give Easterly deviation, but with ship's head in opposite direction, it would cause Westerly deviation. − C has the reverse effect. This co-efficient is mostly due to sub-permanent magnetism. It disappears on East and West by compass.

B or C preponderates in the sum total of the deviation on any one point, according to which of the cardinal points the ship's head may be nearest.

Co-efficient D. Co-efficient D indicates *quadrantal* deviation, and is a maximum with ship's head on N.E., S.E., S.W., and N.W. by *compass*. The effect is of greater complexity than that of B or C, for whereas these act respectively throughout an entire *semicircle*, and retain the same name in that semicircle, D waxes and wanes in each *quadrant*, and changes its name as it passes from one to the other. It is therefore twice as variable as B or C. This is alluded to on page 610.

Ordinarily, the sign of D is +, indeed, 999 times out of 1,000 it is so. With ship's head anywhere between North and East and South and West, it causes Easterly deviation. In the other two quadrants it causes Westerly deviation. − D (very rare) produces opposite effects.

D is caused by the induced magnetism of horizontal iron running in a fore and aft or athwartship direction, such as beams, stringer plates, &c. It disappears on the cardinal points.

Co-efficient E. Co-efficient E indicates *quadrantal* deviation, and is a maximum with ship's head on North, South, East, and West. Its sphere of action is greatest where that of D is least. It resembles D in all essentials except that it is generally small in amount, and therefore seldom requires attention. E is caused by the induced magnetism of horizontal iron lying at an angle of 45° to the fore and aft line, such as *diagonal* tie-plates, &c.; and upon the direction of this iron depends the sign of **E**; for example, iron running from the starboard quarter towards the port bow will produce + **E**, but from the port quarter towards the starboard bow it will produce − **E**.

Both **D** and **E** produce opposite effects in the case of *divided* iron. For example, an ordinary deck beam produces + **D**, but if cut for a skylight or other aperture, and the compass be placed *between* the divided portions, − **D** would be the result. **Divided iron.**

So also with **E**. Whatever the sign might be with continuous iron, it would be the contrary with divided iron. **E** disappears on the inter-cardinal points.

Now, to some people the foregoing may appear hopelessly involved. + and − figure to such an extent, and are reversed so often according to the conditions of the moment, that it would appear to them to be useless even to *try* and remember such a tangle. The writer most cordially agrees. It *would* be useless to try and *remember* so many varying elements. But it is the simplest thing in the world to get to *understand* them, and so be able to *reason them out* when required. Quite the very best way of doing this is by a working model, and the very best model for illustrating all the phases of a ship's magnetism, and shewing their treatment in connection with compass adjustment, is Captain George Beall's Deviascope.* Its price, however, puts it beyond the reach of individuals, but schools avail themselves of it, and presumably so, also, do the Board of Trade examiners. **Abhor cramming.**

There is no reason, however, why individual students should not resort to more simple expedients at a cost of nothing at all. "Where there's a will, there's a way."

When the writer was studying the compass question, his 3-foot model was a flat board, which the ship's carpenter accommodatingly shaped at each end to resemble the boat of one's boyhood. The centre was slightly dished out to take a small compass (borrowed), and red and blue colour was daubed on the board to suit any particular idea as to the ship's magnetism. The correcting magnets were made out of spare compass needles (ends duly coloured), rod-iron of suitable lengths obtained from an engineer friend, and a few small iron globes of sizes. These last were the only bought articles of the lot. No doubt the apparatus was **Bad workmen blame their tools.**

* Messrs. H. Hughes and Son, of Fenchurch St., London, are the sole makers.

Pleasant Reminiscences.

very primitive, but it served its purpose well, and years afterwards a similar one illustrated many a lecture to shipmates on board the s.s. *City of Mecca.*

Having formally introduced the five co-efficients, it is now time to say how they are obtained. To do this in the ordinary way, the ship must be swung and the deviation carefully ascertained with her head on the eight principal points *by compass.* It is better that she should be swung twice, if possible—once in each direction, and the mean taken; this gets rid of the "Gaussin error," which is merely a diminutive effect of "Retained" magnetism. In the process of swinging there is no time for this error to grow large; about a degree is the *usual* thing, though it *may* be double that amount on rare occasions.

We will imagine the ship to have been swung, and that the subjoined Table shows the result.

Deviation on the eight principal points.

Ship's head *by Compass.*	Deviation.	Ship's head *by Compass.*	Deviation.
North	− 6° 30′	South	+ 11° 30′
N.E.	− 10 39	S.W.	+ 22 39
East	− 14 30	West	+ 14 30
S.E.	− 7 21	N.W.	+ 0 21

Easterly deviation is always represented by +, and Westerly deviation by —. It will be noticed that the deviation in the Table is given to degrees and *minutes.* This is merely for purpose of illustration, as will be discovered further on. In practice it would be laughable. Now to find the co-efficients.

A.—Add together (algebraically) the four deviations determined with the ship's head on the cardinal points *by compass,* and divide by 4. For *Algebraic* addition *see* page 712.

EXAMPLE.

North	− 6° 30′	South	+ 11° 30′
East	− 14 30	West	+ 14 30
	−21° 00′		+ 26 00
			− 21 00
		4)	+ 5 00
		A =	+ 1° 15′

B.—Add together the deviations determined with the ship's head East and West *by compass*, reversing the sign of the latter, and divide by 2. Co-efficient B.

EXAMPLE.

East	− 14° 30′	
West	− 14 30	(sign reversed.)
2)	− 29 00	
B =	− 14° 30′	

C.—Add together the deviations determined with the ship's head North and South *by compass*, reversing the sign of the latter, and divide by 2. Co-efficient C

EXAMPLE.

North	− 6° 30′	
South	− 11 30	(sign reversed.)
2)	− 18 00	
C =	− 9° 00′	

NOTE:—To avoid "heeling error" it is essential that the ship should be upright, more particularly when the deviation is determined on North and South. Should the ship be swung in both directions, and with contrary heel and to the same extent, the mean deviation will be free from heeling error.

D.—Add together (algebraically) the deviations determined with the ship's head *by compass* on N.E., S.W., S.E., and N.W., reversing the signs of the two latter, and divide by 4. Co-efficient D.

EXAMPLE.

N.E.	− 10° 39′	
N.W.	− 0 21	(sign reversed.)
	− 11° 00′	

S.W.	+ 22° 39′	
S.E.	+ 7 21	(sign reversed.)
	+ 30 00	
	− 11 00	
4)	+ 19 00	
D =	+ 4° 45′	

E.—Add together (algebraically) the deviations determined with the ship's head *by compass* on North, South, East, and West, reversing the signs of the two latter, and divide by 4. Co-efficient E

EXAMPLE.

North	− 6° 30′	
West	− 14 30	(sign reversed.)
	− 21° 00′	

South	+ 11° 30′	
East	+ 14 30	(sign reversed.)
	+ 26 00	
	− 21 00	
4)	+ 5 00	
E =	+ 1° 15′	

These, then, are the five Co-efficients, and with their aid it is quite a simple matter to form a complete Deviation Table; that is to say, that, starting with the Deviation known only on the eight principal points, it becomes possible and easy to *correctly* fill up the other 24.

The following is the method by calculation. The reader will please take the Table on page 641 by way of illustration.

Size of form.

First and foremost, rule the form in blank, allowing yourself plenty of room; a sheet of foolscap will just do for a neat penman Next, write in the points of the compass on the left, and the ascertained Co-efficients along the top—each with its proper sign. As you already know the deviation on the 8 principal points, you can enter them *at once*, with their proper signs, in column No. 7. Then proceed with the skeleton of the Table as follows:—

A (+ 1° 15′) being constant, there is nothing to do but fill in the column right down to the bottom without alteration of any kind.

B is entered at its full value (14° 30′) on the East and West points. On East, the sign (−) is retained; on West it is reversed. Write 0° 0′ against North and South. Prefix the − sign to each vacant space in the eastern *semicircle,* and the + sign to each vacant space in the western *semicircle.*

C is entered at its full value (9° 0′) on the North and South points. On North, the sign (−) is retained; on South it is reversed. Write 0° 0′ against East and West. Prefix the − sign to each vacant space in the northern *semicircle,* and the + sign to each vacant space in the southern *semicircle.*

D is entered at its full value (4° 45′) on *each* of the inter-cardinal points. On N.E. and S.W. the sign (+) is retained; on S.E. and N.W. it is reversed. Write 0° 0′ against North, South, East, and West. Prefix the + sign to each vacant space in the *quadrant* between North and East, and South and West; and the − sign to each vacant space in the other two *quadrants.*

E is entered at its full value (1° 15′) on each of the cardinal points. On North and South the sign (+) is retained; on East and West it is reversed. Write 0° 0′ against N.E., S.E., S.W., and N.W. Prefix the + sign to each vacant space in the *quadrant* between N.W. and N.E., and between S.E. and S.W., and the − sign to each vacant space in the other two *quadrants.*

The Table is now well advanced, and the rest is quite simple. **A** is already finished with.

To compute **B**:—

Turn it into *tenths* of a degree by dividing the minutes by 6, and annexing the quotient to the degrees. Thus 14° 30′ becomes 145 tenths. Open the Traverse Tables at the given number of points. Take out the *Departure* corresponding to 145 in the Distance column. Put the decimal point in its proper place, and restore the tenths to minutes by multiplying by 6. Thus, for, say, N.N.E. (2 points), the *Departure* corresponding to 145 in a Distance column is 55·5; shifting the decimal point we get 5°·55 as the value of **B** on N.N.E. To restore to minutes, multiply ·55 by 6, and we get 33′. The complete answer is therefore 5° 33′ as per Table, and so on with the remaining points.

Handiness of decimals, and utility of Traverse Tables.

To compute **C**:—

The process is identical with the preceding, except that the deviation due to **C** on any given point is to be taken from the *Latitude* column. Thus 9° becomes 90 tenths, and supposing the deviation due to this co-efficient is required on N.E. by E. (5 points), we find in a *Latitude* column, abreast of 90 in a Distance column, the number 50·0. Shifting the decimal point we get 5° 0′ ready for insertion, as this time there is no decimal to convert into minutes.

To compute **D**:—

Proceed as before, but enter the Traverse Tables with *double* the number of points that the ship's head is from *either* of the cardinal points, and the *Departure* will give the number of tenths of a degree of deviation due to this co-efficient. For example: required to know the value of **D** on N.E. by E. This is 3 points from East, so the Tables must be opened at 6 points. The full value of **D** is 4° 45′, which may be regarded either as 4·7 or 4·8; but to be exact, look for 47 in the Distance column, and the corresponding *Departure* is found to be 43·4. Then look for 48, and the corresponding *Departure* is 44·4. The *mean* is 43·9. Shifting the decimal point we get 4·39 = 4° 23′ as the value of the deviation caused by **D** on N.E. by E.

To compute **E**:—

Proceed as with **D**, except that the required number is to be taken from the *Latitude* column. Required to know the value of the deviation due to **E** on, say, W. by N. This is one point from West, so open the Traverse Tables at 2 points. The full value of **E** is 1° 15′. Turning it into tenths, we get 1°·2 or 1°·3, whichever you choose, but it will be convenient to consider it as 125. With this in the Distance column, the corresponding quan-

Ship's Head by Compass.	CO-EFFICIENTS of iron ship "Lodestone." A = + 1° 15′	B = − 14° 30′	C = − 9° 00′	D = + 4° 45′	E = + 1° 15′	Total Deviation.	Ship's Head Magnetic.
North.	+ 1° 15′	0° 00′	− 9° 00′	0° 00′	+ 1° 15′	− 6° 30′	N. 6° 30′ W.
N. by E.	+ 1 15	− 2 50	− 8 48	+ 1 49	+ 1 09	− 7 25	N. 3 50 E.
N.N.E.	+ 1 15	− 5 33	− 8 18	+ 3 21	+ 0 53	− 8 22	N. 14 08 E.
N.E. by N.	+ 1 15	− 8 04	− 7 30	+ 4 23	+ 0 29	− 9 27	N. 24 18 E.
N.E.	+ 1 15	− 10 15	− 6 24	+ 4 45	0 00	− 10 39	N. 34 21 E.
N.E. by E.	+ 1 15	− 12 04	− 5 00	+ 4 23	− 0 29	− 11 55	N. 44 20 E.
E.N.E.	+ 1 15	− 13 24	− 3 24	+ 3 21	− 0 53	− 13 05	N. 54 25 E.
E. by N.	+ 1 15	− 14 13	− 1 48	+ 1 49	− 1 09	− 14 06	N. 64 39 E.
East.	+ 1 15	− 14 30	0 00	0 00	− 1 15	− 14 30	N. 75 30 E.
E. by S.	+ 1 15	− 14 13	+ 1 48	− 1 49	− 1 09	− 14 08	N. 87 07 E.
E.S.E.	+ 1 15	− 13 24	+ 3 24	− 3 21	− 0 53	− 12 59	S. 80 29 E.
S.E. by E.	+ 1 15	− 12 04	+ 5 00	− 4 23	− 0 29	− 10 41	S. 66 56 E.
S.E.	+ 1 15	− 10 15	+ 6 24	− 4 45	0 00	− 7 21	S. 52 21 E.
S.E. by S.	+ 1 15	− 8 04	+ 7 30	− 4 23	+ 0 29	− 3 13	S. 36 58 E.
S.S.E.	+ 1 15	− 5 33	+ 8 18	− 3 21	+ 0 53	+ 1 32	S. 20 58 E.
S. by E.	+ 1 15	− 2 50	+ 8 48	− 1 49	+ 1 09	+ 6 33	S. 4 42 E.
South.	+ 1 15	0 00	+ 9 00	0 00	+ 1 15	+ 11 30	S. 11 30 W.
S. by W.	+ 1 15	+ 2 50	+ 8 48	+ 1 49	+ 1 09	+ 15 51	S. 27 06 W.
S.S.W.	+ 1 15	+ 5 33	+ 8 18	+ 3 21	+ 0 53	+ 19 20	S. 41 50 W.
S.W. by S.	+ 1 15	+ 8 04	+ 7 30	+ 4 23	+ 0 29	+ 21 41	S. 55 26 W.
S.W.	+ 1 15	+ 10 15	+ 6 24	+ 4 45	0 00	+ 22 39	S. 67 39 W.
S.W. by W.	+ 1 15	+ 12 04	+ 5 00	+ 4 23	− 0 29	+ 22 13	S. 78 28 W.
W.S.W.	+ 1 15	+ 13 24	+ 3 24	+ 3 21	− 0 53	+ 20 31	S. 88 01 W.
W. by S.	+ 1 15	+ 14 13	+ 1 48	+ 1 49	− 1 09	+ 17 56	N. 83 19 W.
West.	+ 1 15	+ 14 30	0 00	0 00	− 1 15	+ 14 30	N. 75 30 W.
W. by N.	+ 1 15	+ 14 13	− 1 48	− 1 49	− 1 09	+ 10 42	N. 68 03 W.
W.N.W.	+ 1 15	+ 13 24	− 3 24	− 3 21	− 0 53	+ 7 1	N. 60 29 W.
N.W. by W.	+ 1 15	+ 12 04	− 5 00	− 4 23	− 0 29	+ 3 27	N. 52 48 W.
N.W.	+ 1 15	+ 10 15	− 6 24	− 4 45	0 00	+ 0 21	N. 44 39 W.
N.W. by N.	+ 1 15	+ 8 04	− 7 30	− 4 23	+ 0 29	− 2 05	N. 35 50 W.
N.N.W.	+ 1 15	+ 5 33	− 8 18	− 3 21	+ 0 53	− 3 58	N. 26 28 W.
N. by W.	+ 1 15	+ 2 50	− 8 48	− 1 49	+ 1 09	− 5 23	N. 16 38 W.

tity in the *Latitude* column is 115·5. Shifting the decimal point, we get 1°·155 = 1° 9′ as the required value on W. by N.

A glance at the Table will shew that there is much less trouble in taking out these values than one would at first imagine, for it will be apparent that **B** and **C** are only required for one-fourth of the entire circle, the remainder being merely a repetition. So also with **D** and **E**, only more so; for in their case the values have merely to be taken out for the half of one quadrant. To fill in the remainder is repetition. The Table is therefore *not nearly* so big a job as it looks. The secret is to do it *systematically.* **Easier than it looks.**

Having the deviations due to the co-efficients, they are summed up algebraically, and entered in column No. 7 against each of the remaining 24 points. **For *Algebra*, see last chapter of all**

Column No. 8 completes the Table, and it is hardly necessary to explain how it is formed. It speaks for itself.

The formation of this Table and the construction of Barrett's diagram afford excellent practice for the student. The one serves to check the other. It would be an advantage always to tackle the diagram *first,* seeing that the accuracy of the values depends upon the accuracy of the measurements made with the dividers. By taking them in this order, there can be no bias or cooking, and it will be interesting to the operator to see how closely his handywork approaches the more exact method by the Traverse Tables.

So far, in the process of compass adjustment, four methods of ascertaining the deviation have been referred to, namely, Azimuths of the heavenly bodies, Transit-bearings of shore objects, Distant landmarks, and the use of Lord Kelvin's Deflector. This instrument has been described in Part I., but the details of manipulation are not given, because it is accompanied by a small pamphlet of instructions. The *principle,* however, has been briefly explained, and in view of what now follows it is well to repeat it.* This will enable the reader to see the analogy between the principle involved in the use of the Deflector, and the principle involved in the method about to be described. Looking at the date, the truth of the adage comes home that "There is nothing new under the sun." The follow- **Recapitulation of methods.**

* If the directive force on the compass is the same for all courses of the ship, there can be no error of the compass on any course. *Per contra,* where the directive force is found to be unequal, there must be deviation.

ing letter is taken from a back number of *Naval Science*, by kind permission of the then publishers.*

NEW MODE OF ASCERTAINING THE DEVIATION OF THE COMPASS IN STEAMERS.

To the Editor of "Naval Science."

SIR,—Will you allow me to describe in *Naval Science* a new mode of obtaining a complete table of the deviations of the compass in steamers which has recently occurred to me, and which may be used at sea at any time during moderate weather! It does not require either a distant object of known bearing or any celestial observation. It can be used as well at night or in a fog as in broad daylight, and the only instrument required in addition to the compass of which the deviations are to be ascertained, is an ordinary watch with a seconds hand.

This at first sight will appear to many as an impossibility; but I hope to show your nautical readers, without going into much detail, that the plan is not only practicable, but easy.

It is generally known among seamen that an uncorrected or only partially corrected compass, in an iron ship, does not, as the ship turns round, indicate the exact angle through which she has moved. Thus, in some directions of the ship's head, an actual movement through an angle of 20 degrees may, according to the compass, be so little as 10 degrees, or it may be so much as 30 degrees; this difference, plus or minus, between the actual and the apparent movement being in reality that portion of the total deviation which belongs to the particular angle through which the ship has moved. To ascertain the deviation of the compass, therefore, we only require some mode of measuring the real angle through which the ship moves in every part of the circle.

Let us suppose, then, that a steamer's helm, while she is under way in moderate weather, is placed and held steadily to starboard or port sufficiently long to cause her to describe a complete circle in from twelve to twenty minutes; and let it be granted that, with moderate care, the steamer's speed during this time will be sensibly uniform, it is then evident that, as equal parts of the circle will be described in equal times, we shall have a sufficiently exact measure of degrees of arc in terms of seconds of time. Thus, if the circle be completed in twelve minutes or 720 seconds of time, each degree will be represented by two seconds of time; if the circle be completed in eighteen minutes, each degree will be represented by three seconds of time.

In using this process, if it is desired to ascertain the deviation of the compass on every point, note must be made of each point and the time to the nearest second at which it passes the lubber-line. If the deviation on each second point is considered sufficient, each second point and the time at which it passes the lubber-line must be noted. It is not requisite that any particular points should be taken, but, for the reason to be presently stated, it is essential that several should be noted, and that they should be pretty equally distributed round the compass.

It does not affect the final result at what part of the circle or point of the compass the operation is commenced, but it will be found convenient to begin at north and to record the compass observations in degrees reckoned in the usual way, from north by way of east, from 0° to 360°; and to reckon the time in degrees of arc, counting from the same starting point.

The differences between the number of degrees by compass at any point and the number of degrees by time, recorded as *plus* or *minus*, will give a deviation table, but, usually, this table will have a considerable index error, as it has, so far, been constructed on the assumption that there is no error at the point at which the operation commenced. The next part of the process is to ascertain this index error and to apply it to each observation in the table in the usual manner—namely, by dividing the algebraic sum of all the observed deviations by the number of the observations taken, and by applying

* Messrs. Lockwood and Co., London.

the index error thus obtained to each of the deviations according to its sign. The index error is, of course, the deviation that belongs to that point of the compass at which the operation was commenced.

This brief description comprises all that is necessary to "swing ship" by the new process, but, as a steamer while turning has always a slight list, it is recommended that she should be put round in opposite directions, and that a mean of the two deviation tables thus obtained should be taken as the correct one. It is also recommended that the observations should be taken on every point of the compass as the best means of ascertaining most correctly the index error which belongs to the process.

It would be useless for anyone to try this method with a compass that was not steady and in good order. The compass should also be gently and uniformly tapped during the whole of the process, so as to reduce the friction on the pivot, and thus check, or rather prevent any tendency to oscillation of the card.—Yours very obediently,

W. W. RUNDELL.

Underwriters' Rooms, Liverpool,
13th September, 1873.

It is apparent that there is nothing impracticable in Mr. Rundell's suggestion, and the writer regrets that the method was unknown to him during his career at sea. To avoid the helm-list referred to in the letter, the time required to make the complete circle might be increased to 30m., which would allow a degree to be represented by 5s. Extending the time would diminish the rudder-angle, and otherwise materially conduce to accuracy. The total time required to make the circle in each direction would be about 1¼ hours. From its small friction-error, Lord Kelvin's compass would be particularly well suited to this experiment. The publication of *Naval Science* ceased some years ago, more's the pity, as it was a really first-class magazine.

A 30-minute circle.

There have been many discussions from time to time as to the propriety of adjusting compasses by magnets, some men contending that the better plan was to leave the compass to follow its own bent, and to navigate by the aid of a Table, giving the *natural* deviation; but iron is now so largely and *recklessly* used in deck fittings, &c., that compass errors have assumed a magnitude quite unknown when iron vessels first came into vogue. Formerly, also, more care was exercised in the selection of suitable positions for the compass, and the theory of adjustment was not so well understood. Thus it is that adjustment now cannot be dispensed with, or the majority of compasses would be quite unmanageable. Scarcely anyone, now-a-days, will be found so ignorant as to advocate non-adjustment.

Ancient views

Sir George Airy, late Astronomer-Royal, thus sums up the advantages in favour of compass adjustment:—

Advantages of Compass Adjustment—Sir Geo. Airy.

"NON-CORRECTED COMPASSES.
Using a Table of Errors.

(1.) The directive power on the compass is extremely different on different courses.

(2.) The principal part of the tabulated errors arises from sub-permanent magnetism, whose effects in producing Deviation vary greatly in different parts of the earth.

(3.) It is therefore absolutely necessary, from time to time, to make a new table of errors, by observations in numerous positions (not fewer than eight) of the ship's head.

(4.) In difficult navigation, as in the channels of the Thames or the Mersey, especially with frequent tacks, the use of a Table of Errors would be attended with great danger."

"CORRECTED COMPASSES.
The Binnacle being adjustable.

(1.) The directive power on the needle is sensibly constant.

(2.) The magnets, which perfectly correct the sub-permanent magnetism in one place, will also perfectly correct it in another.

(3.) Only when there is suspicion of change in the ship's magnetism are new observations necessary, and then two are sufficient.

(4.) In any hydrographical difficulty, the corrected compass is right on all tacks, and its use is perfectly simple."

No. 2 of the above applies equally to the Deviation arising from the inductive magnetism of vertical iron.

Electric lighting

Of late years the much-tortured compass has been subjected to a fresh source of disturbance, very much of the "snake in the grass" type. Of course *Electric Lighting* is referred to. So important do the Committee of Lloyd's Register of British and Foreign Shipping consider the subject, that they have issued proposals for the consideration of Shipowners and others. The following are those which bear upon the compass:—

(1). **POSITION OF DYNAMOS AND OF ELECTRIC MOTORS.**—Dynamos and Electric Motors should be placed as far as possible from all compasses, and should be at least 30 feet from the standard compass.

(2). **CABLES.**—In vessels fitted with continuous current dynamos, and wired on the single-wire system, no single cable should be carried within 15 feet of any compass, and cables conveying a heavy current should be fixed at still greater distance. If it is necessary to fix the cables within this distance, then for all parts of the vessel lighted from this cable the double-wire system should be adopted, the return wire being carried as near the flow as possible in the vicinity of the compasses.

(3). **ADJUSTMENT OF COMPASSES.**—The compasses should be adjusted with the dynamo not working, after which the vessel's head should be put upon the different courses, with the dynamo running at full speed, and on each course the indications of the compass should be noted with the dynamo running with open circuit and with all possible combinations of the current switched "on" and "off" all circuits passing near the compasses. These indications should be compared with those obtained with the dynamo stopped, and any serious deflections of the compasses remedied before the vessel sails. In vessels wired on the "double-wire" system this is not so important as in those wired on the "single-wire" system, but at least the effect should be tested of the dynamo running with open circuit.

It is evident from the suggestions in (3) that if the adjuster carries them out faithfully—as he should do—he has his work cut out for him. This question of Electric Lighting should be looked into at the time of preparing the specification for a new vessel, or at the time of contracting for an installation in the case of an old one. It is no use waiting till the Dynamos have been put in position and the bunches of wires cased in. Let Navigators bear this in mind, and take Time by the forelock.

Look ahead.

REMEMBER

THAT HOWEVER WELL A COMPASS MAY BE ADJUSTED, OBSERVATIONS FOR DEVIATION SHOULD BE MADE EVERY WATCH AS A MATTER OF ORDINARY ROUTINE. SPECIAL OBSERVATIONS SHOULD BE MADE AFTER ANY CHANGE OF COURSE EXCEEDING ONE POINT. IT IS NOT POSSIBLE TO COMPENSATE "RETAINED" MAGNETISM, AND IN SOME SHIPS THE DEVIATION FROM THIS CAUSE IS VERY LARGE.

Final injunction.

CHAPTER XVII.

SHAPING THE COURSE.

At first sight this seems a simple enough affair, and yet there are often, if not always, many matters of moment which require due deliberation before the actual Course to be steered can be given to the helmsman.

Course now set in Degrees instead of Quarter Points

Until within a recent period, the Course was set to the nearest quarter point, and with short chunks of vessels—which, especially when running, yawed a handful of points either way—this was near enough, perhaps; but the old "three-handled serving mallet" has given way to the "Four-Poster" and the "tea-kettle." Navigation of to-day demands much greater precision; and, in large steamers at all events, the Course is now rarely given otherwise than in *degrees*. Indeed, some of the new pattern compass-cards are so graduated as to leave it no longer optional.

To the man unaccustomed to it, this steering to degrees seems rather absurd, as he is almost certain to regard it as a vain striving after the impossible. But when he discovers that the long and finely-modelled vessels of present build actually *make* the desired Course, allowing for current and leeway, his unbelief gives place to astonishment, and he is fain to admit that the world progresses.

The True Course.

To conduct a vessel from one place to another, when out of sight of land, involves a knowledge of the TRUE COURSE, the MAGNETIC COURSE, and the COMPASS COURSE.

The TRUE COURSE is the angle made with the meridian by a straight line on Mercator, drawn to connect the ship's position with the place bound to. This angle is readily ascertained, after the manner already described, by means of the Protractor, Field's Parallel Ruler, or the common ebony one (the latter being used in conjunction with the *true* compass diagram on the chart); also by calculation.

The Magnetic Course. The MAGNETIC COURSE is derived from the True Course by applying to it the Variation at place of ship, which may be obtained with accuracy from the *Magnetic Chart of the World.* Easterly variation is applied to the left, and westerly variation to the right of the true course. Thus, if the TRUE COURSE is North, and the variation is 20° Easterly, the MAGNETIC COURSE would be N. 20° W.

The Compass Course. The COMPASS COURSE, or course to steer, is found by applying the Deviation to the MAGNETIC COURSE—Easterly to the left, and Westerly to the right, *just as you would with Variation.* Consequently, when these two elements in the Course are of the *same* name, they are to be applied in the *same* direction, and *vice versâ.*

***Plus* and *minus* signs used to express the *name* of Variation or Deviation.** It is usual to speak of Easterly Variation and Deviation as *plus* (+), and of Westerly Variation and Deviation as *minus* (−). Thus, if the MAGNETIC COURSE is N. 20° W., and the Deviation is − 20°, the COMPASS COURSE would be North.

This manner of distinguishing the name of the Variation and Deviation by the *plus* and *minus* signs, though purely arbitrary, is convenient when one has become accustomed to it. Thus, in the example just given, we have North for the TRUE COURSE, with + 20° of Variation, and − 20° of Deviation: since, as many are aware, these two quantities neutralize each other, being equal in amount, but of opposite names, it is evident that the COMPASS COURSE must be North, or the same as the TRUE COURSE.

As a further illustration, let the TRUE COURSE be N. 40° E., the Variation − 38°, and the Deviation + 8°. Then, taking their difference (being of contrary names), we have − 30° as the remainder; or, in other words, the *correction* is 30° Wly., which makes the COMPASS COURSE N. 70° E.

Variation	− 38°	Being of contrary names, take their difference.
Deviation	+ 8°	
Correction	− 30°	Apply to the right, being Westerly.
TRUE COURSE . . .	N. 40° E.	
COMPASS COURSE . .	N. 70° E.	

The tyro must guard against the mistake of using the prefixes *plus* and *minus* in their arithmetical sense, since, in the process just described, a *minus* correction, though subtractive in the S.E and N.W. quadrants, is additive in the N.E. and S.W. quadrants.*

To give a case where the Variation and Deviation have the same sign, and consequently act in unison, let the TRUE COURSE be S. 75° W., the Variation + 24°, and the Deviation + 6°; the *Correction* would be + 30°, making the COMPASS COURSE S. 45° W.

Variation	+ 24°	Being of same name, add them together.
Deviation	+ 6°	
Correction	+ 30°	Apply to the left, being Easterly.
TRUE COURSE . . .	S. 75° W.	
COMPASS COURSE . .	S. 45° W.	

In all iron vessels, and indeed in most wooden ones (since the compasses, even of the latter, are seldom altogether free from the influence of iron), the above "rendering down" of the TRUE COURSE into the COMPASS COURSE is absolutely necessary.

An important distinction.

The above is sound, so far as it goes: nevertheless, there is a flaw which might escape detection if attention were not drawn to it. Where the compass is *un*compensated, or where the deviations of an imperfectly compensated compass happen to be large, the Navigator is embarrassed by the fact that there is often a large difference in the amount of deviation employed to *shape* a course, as compared with that employed to *correct* a course

* The reader will remember that when the daily rate or the accumulated error of a chronometer is marked with the prefix +, it means that the one is gaining, and that the other is fast, and *not* as an indication that they are quantities to be *added*.

already steered. In other words, when a ship's head is, say, North *magnetic*, it probably points in a very different direction to what it does when her head is North *by compass*. Now, if the deviation be ascertained when ship's head is in *each* of these two positions, it will not be found the same; hence the amount to be applied to change a *compass* course into a *magnetic* course will be less or more than that employed in the reverse operation.

This will be apparent when it is remembered that the magnetic influences at work on the compass vary with the precise direction of the ship's head. Let us imagine a case. With ship's head North, *by uncompensated compass*, the deviation is three points westerly. Her head, therefore, is really N.W. by N. *magnetic*. But we want to know what the deviation is with her head pointing North, *magnetic*. She must, therefore, be turned three whole points to the right—not by compass, but *actually* three points. Now, this turning of the ship to so great an extent will bring stronger or weaker influences to bear upon the compass than before, with the result that the deviation will be quite different: in fact, though we *know* the ship to have moved *exactly* three points to the right, the *compass* might make it appear that she had moved only two points, or, on the other hand, that she had moved as many as four points. In all compass work, therefore, it is important to realize the distinction between the direction of ship's head *by compass* and ship's head *magnetic*. The two directions may differ by many—not degrees but—points.

Referring back to the two figured examples, it will *now* be noticed that, although the amount of deviation is specified, the reader is not informed whether it was ascertained with ship's head on a certain point *by compass*, or with ship's head on same point *magnetic*. In each of the examples, the deviation is so small that the difference would probably be insensible; but with uncompensated compasses it would be otherwise, and some plan would have to be adopted for the conversion of *magnetic* courses into *compass* courses, and the contrary, as might be required.

There are many modes of doing this:

1. Napier's diagram, with which all certificated officers are familiar.
2. Arch. Smith's "straight line" method, which may be likened unto a ladder with the rungs at various angles.
3. A compass card, its circumference lying ¾ of an inch or so within an outer circle representing the *magnetic* points of the compass.

Arch. Smith's straight-line method.

Of the three, the writer much prefers Arch. Smith's method, as any fellow can easily construct it for himself; whereas it requires a man who has lived in the same street with a draughtsman to produce the others.

Course to steer.

To correct the course steered.

In the case of the method advocated, it is convenient to construct *two* distinct ladders—one to shew the rungs starting from the whole points *mag.*, and arriving where they may on the *compass* side; the other to shew the rungs starting from the whole points *by compass*, and fetching across where they may on the *mag.* side.

Now that adjustment, having outlived prejudice, is universally resorted to, these contrivances are hardly wanted; all the same, it is well to know and understand them.

How to correct M. into Compass Courses and the contrary.

To construct Arch. Smith's method, draw 3 columns (4 vertical lines) side by side, each about an inch in width. Leave the middle one blank. Divide and rule the right and left columns each into 32 parts, and write in rotation the points of the compass, beginning both sides with North at top. Head the left column "Compass Course," and the right column "Magnetic Course." Then, if the deviation has been determined with ship's head on each whole point *by compass*, connect the *points* on the left with the *degrees* on the right according to the amount of deviation. For example, if, with ship's head North *by compass*, the deviation is + 6°, the line (or rung) would start from North on the left, and be drawn slantingly across to N. 6° E. on the right.

Or if, with ship's head North *magnetic* by Pelorus (see page 135), the compass deviation is + 10°, the line would start from North on the right, and be drawn across to N. 10° W. on the left, and so on. Rule a form for each.

The navigating outfit of a foreign-going vessel is incomplete without a Magnetic Chart of the World. The Admiralty publish one, giving single degree curves of equal Variation,* and many, if not all, of their Ocean Charts give the curves for every fifth degree. On the first-named, which is now issued for the year 1907, there is a chartlet shewing the *annual change* in the Variation.† A knowledge of this change is important, as in many parts of the world it is very rapid, and after a few years the correction becomes quite a consideration. Thus, on the North Coast of Ireland the Variation is decreasing at the rate of about 1° in ten years, which soon mounts up; and in the English Channel the rate is about 1° in eleven years.

Magnetic Chart of the World.

Annual change in the Variation.

Pilots are not always acquainted with this peculiarity of terrestrial magnetism, and, in consequence, some of the old ones give courses which may have been the correct thing when they were apprentices, but are so no longer. For example, quite recently a very experienced channel pilot gave the *magnetic* bearing of the South Foreland lights when in one as W. by N., though in reality it is now little better than W. ½ N.; and on being told so, said he was certain he was right, as he recollected hearing it thus given *since he was a boy, and he was not aware that the lighthouses had ever been moved from their original places.*

Liability to change of Mag. bearings

Where there is a wide expanse of shoal water, and only a narrow channel, half a point in thick weather, or at night, may just make all the difference between danger and safety. In a run of only ten miles it would throw the ship *one mile* out of her proper course.

Certain cheap and useful almanacs, much in favour with coasters, contain tables of Channel Courses; but it is evident from what has just been stated, that in a comparatively short time these tables must need revision. A man *with* a chart does not require such dry nursing, and a ship navigated *without* one is not safe.

Tables of Channel Courses.

There are parts of the world, also, where a trifling change in the ship's position means a comparatively large change in the amount of Variation. These localities are easily recognised on the Magnetic Chart by the crowding together of the Variation curves; and when the ship's track happens to lie *across* these curves, it is necessary to be more than usually careful with the compass course.

* These are termed "Isogonic Curves."

† Variation curves are also given on the monthly Meteorological Charts of the North Atlantic and of the Indian Ocean, issued by the British Meteorological Office; and on the monthly Pilot Charts of the North Atlantic and of the North Pacific, issued by the United States Hydrographic Office; as also on similar charts emanating from the Deutsche Seewarte.

Between Nantucket and Cape Race, for example, an Atlantic "Greyhound" will increase the Variation as much as 12° in a single day's run; and a want of due appreciation of the rapidity of change, through not having a Variation Chart, has probably been *one* of the causes which formerly led to so many cases of stranding in this neighbourhood. When shaping a course in such a locality, it is advisable to measure off on the Magnetic Chart the probable run during the ensuing 24 hours, and so ascertain the change which will take place in the amount of the Variation in that time; then alter course every "four bells" or "eight bells" to the required extent. Supposing the change of Variation in a day's run to be 12°, it would be properly met by altering the course 1° every two hours. This is a long way better than employing the *mean* value of the Variation at both ends of the run, and steering *one course throughout.*

Periodical change of course to allow for geographical change of Variation.

It is evident that if this last mentioned and more common plan should be pursued, the vessel's track will be actually a curve instead of a straight line; and if the course should happen to be a "fine" one, set to pass within a few miles of an outlying shoal, this loose manner of doing it might lead to disaster *in those cases where the convex or outer side of the curve chanced to lie on the same side as the danger.*

Sometimes, when steering on a Great Circle track, the Variation accidentally alters in the same proportion as the TRUE COURSE, so that there is no necessity for changing the COMPASS COURSE as long as this condition prevails.

Retained Magnetism the possible cause of Wreck.

The reader now comes to a point demanding special attention. At first it may be a little difficult to understand, but its importance will not allow it to be overlooked. It has reference to this periodical changing of the course in accordance with the increase or decrease of Variation as the vessel progresses, and the bothering effects of "Retained" magnetism. Many iron steamers bound to New York have got ashore at various times on the "Georges" and Sable Island, when those in command thought they were well to the southward. An unusual set of current generally gets the blame in these cases; the writer hopes to make it clear, however, that current was not *necessarily* the cause of the stranding, though it may sometimes have contributed to it. A number of petty things, when acting in the same direction, will produce a large effect; therefore it is necessary to notice those which, *taken by themselves,* would be seemingly trivial.

By consulting the Magnetic Chart it will be seen that the amount of variation on the coasts of New England and Nova Scotia changes very rapidly in a short distance. Now a careful navigator would undoubtedly allow for this by steering a more southerly compass course as the *Westerly Variation decreased;* but he might lose sight of the fact that this change of course—small as it might be—would probably cause almost a proportionate *increase* in the *Easterly Deviation* of his compasses, and thus counteract the effect he desired to produce.

Something which might be overlooked.

It has been shewn in a previous chapter that compasses, when under the influence of "Retained" magnetism, always hang back in the direction of the last course. Now, in vessels crossing the Atlantic, this effect is very marked when, near the end of the passage, they come to be put upon Northerly or Southerly courses; and badly placed compasses, which may be nearly correct, say on West, speedily acquire a large + error as the course is changed towards the South, and a − one as it is changed towards the North, on points where previously no error existed.* This error may grow with such rapidity at every change in the course as very nearly to equal the amount of that change, and thereby frustrate its intention.

"Critical Lines."

The neutral line which separates the + and − Deviations consequent on "Retained" magnetism, may be termed the "Critical line"; and, for Trans-Atlantic steamers, it is about East going one way, and West when going the other.

Near the termination of the Eastern passage the "Retained" magnetism causes a *minus* error on Southerly courses, and a *plus* one on Northerly courses. Reverse this for a west-bound ship.

After a straight run of several days, it is not uncommon, *when the compass is badly placed,* to find the Deviation increase fully half a degree for every degree of alteration in the compass course. For example, on W. by S. ½ S. (by compass) let the Deviation be half a point easterly; but if the course be altered to W.S.W. (by compass), the Deviation will probably increase to three-quarters of a point.

In the first case, the *actual* direction of the ship's head (magnetic) would be W. by S.; and in the second case it would

* Iron is now so much used for deck-fittings of all kinds, that it is often extremely difficult to hit upon even a fairly good place for the compasses. A subject of such *vital importance*, however, should have the best attention of both owners and builders *when the vessel is being designed*. No matter how skilful the Adjuster, or how well made the compass, the latter *cannot* act satisfactorily, if recklessly placed in the vicinity of large bodies of iron. (See chapter on *Compasses*).

be only W. by S. ¼ S. (magnetic), or a *quarter* of a point more to the southward, though *by compass* apparently *half* a point to the southward of the original course. This is one of the great evils of a badly placed compass; and if, in addition to this drawback, the adjustment be of an indifferent character, the evil will be augmented; and when, to the direct effect of the "Retained" magnetism just mentioned, is added the swing of the card produced by the incessant and perhaps violent motion of the ship—*which, in its turn, allows the magnetic disturbing force to act upon the needle at angles which are constantly varying*—to make a good course is clearly a hopeless matter. Under such circumstances the unfortunate Quartermasters too often get roundly rated for careless steering, when the truth is, the best of helmsmen would be puzzled to keep the ship's head straight on *any* course for even two minutes at a time.

Difficulty of steering by a badly placed Compass.

It follows that the navigator, when hauling to the Southward in the locality named, should bear in mind this tendency of the ship to hang to the Westward, and make ample allowance for it, according to existing circumstances. If sun, moon, or stars be visible, azimuths will speedily tell him the true state of the case; but if these are not available, *there is nothing like the Deep-Sea Lead*, which, on the Atlantic coast of the United States, may be depended upon as a reliable guide to avoid danger.

Great Circle Sailing.

We now come to Great Circle Sailing. Most people sturdily refuse to admit that a curve joining any two places constitutes a shorter distance between them than a straight line would; and in this they are perfectly correct. A straight line *is* the shortest distance between any two points; and it is because the opposite idea is conveyed—unintentionally, of course—by an imperfect or badly put explanation of Great Circle Sailing, that there are still sailors who refuse to believe in it; or, if otherwise, it is solely because they have a vague idea that the distance is lessened on account of the degrees of longitude being shorter in high latitudes, forgetting that to arrive at these short degrees of longitude, *additional* degrees of latitude would have to be sailed over. As a matter of fact, the short degrees of longitude have nothing to do with it. When a Great Circle track is laid down on a Mercator Chart, and compared with the straight line * ruled between the same points, it certainly does seem odd to be told that the curved track is the shorter of the two, and that to sail on the

* This straight line is known as a Rhumb Line, or Loxodromic Curve.

straight line (as laid down on the chart) would be to go over unnecessary ground.

The key to the puzzle lies in the fact already stated, that a chart on Mercator projection gives a distorted representation of the earth's surface; and its construction is such, that the shortest distance between any two points on the globe is represented, *not by a straight line*, but by a certain *curved* line termed a Great Circle, or Orthodromic curve, which, if carried round the world, would divide it into two equal portions, and whose plane would in every case pass through its centre. The only exceptions to this rule are those where the straight line on the chart happens to coincide with the equator, or with a meridian, since both these are Great Circles in themselves. It follows, with these exceptions, that a straight line between any two places on a Mercator chart is always a round-about route, being more so in polar regions than in equatorial ones.

Meridians and the Equator the only straight lines on Mercator chart which represent Great Circles

This is easily put to a direct and simple test by means of a good terrestrial globe, say two feet in diameter, and a general chart of the North Atlantic on Mercator projection. Let it be required to find the shortest possible distance between the light-house on the island of Inishtrahul, off the north coast of Ireland, and that on Belle Isle, at the entrance to the Strait of the same name.

On the globe, at each of the places mentioned, drive in a common brass pin, and stretch a piece of fine silk thread tightly from one to the other.* Everyone will admit readily enough that this thread marks the shortest possible road between the two places; there can be no doubt of that. This, then, is the required Great Circle track, and if carried right round the globe, would be found to divide it exactly in half. SMALL CIRCLES, on the other hand, divide the earth into two *unequal* portions, and in consequence their planes cannot pass through its centre. Now examine the angle the thread makes with the various meridians it crosses, and in each case the angle will be seen to be different, *shewing that on a Great Circle the* TRUE COURSE *is continually altering.*

How to determine a Great Circle on the globe.

Next measure with care the exact latitude in which the thread cuts each of the meridians on the globe, and prick off on the chart the several positions thus ascertained. Connect them in a free-hand by pencil lines, and it will be seen that the nearest

* How do carpenters act when they wish to mark a perfectly straight line between two points on a plane?

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be only W. by S. $\frac{1}{4}$ S. (magnetic), or a *quarter* of a point more to the southward, though *by compass* apparently *half* a point to the southward of the original course. This is one of the great evils of a badly placed compass; and if, in addition to this drawback, the adjustment be of an indifferent character, the evil will be augmented; and when, to the direct effect of the "Retained" magnetism just mentioned, is added the swing of the card produced by the incessant and perhaps violent motion of the ship—*which, in its turn, allows the magnetic disturbing force to act upon the needle at angles which are constantly varying*—to make a good course is clearly a hopeless matter. Under such circumstances the unfortunate Quartermasters too often get roundly rated for careless steering, when the truth is, the best of helmsmen would be puzzled to keep the ship's head straight on *any* course for even two minutes at a time.

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* How do carpenters act when they wish to mark a perfectly straight line between two points on a plane?

distance between Inishtrahul and Belle Isle is represented *on the chart* by a curve, differing very widely from the straight line drawn between the two places on the same chart. Next, by way of proof, try what *the straight line on the chart* looks like *when transferred to the globe:* so just reverse the last process, and prick off *on the globe* the latitude of the straight line where it cuts the meridians *on the chart.* Drive in a pin at each such point; and from one to the other, and on their southern or convex side, stretch a second piece of thread, and it will be seen with half an eye that *the straight line on the chart* is actually a round-about one when laid down on the globe. This will be made still more apparent by removing the intermediate row of pins last inserted, when the second thread will become quite slack, which could not be the case if it had been the measure of the shortest distance between the places.*

To prove that the arc of a Great Circle is the shortest distance between two points.

A ship navigated on the straight-line course of the chart, never has her head in the exact direction of the port bound to *until it is in sight.* On the other hand, a vessel's head, when following the Great Circle track, is *all the time* pointed exactly towards the port bound to. If it were only possible at starting to *see* her destination from the masthead, and the ship were steered unswervingly for it, she would, in such a case, be sailing on the Great Circle between the two places; and it would be found by a series of azimuths, taken as the voyage progressed, that the TRUE COURSE—or, in other words, that the angle her track made with the meridian—was continually changing, though the *absolute* direction of the ship's head did not vary a single degree from first to last. But if the vessel were navigated on the Mercator course, it would be seen that, at starting, her head pointed considerably towards the equatorial side of the port bound to, and only turned gradually towards it as the voyage progressed. Azimuths taken from time to time would shew no change in the TRUE COURSE.

True Course on a Great Circle is constantly changing.

True Course on a Mercator track is the same throughout.

This will, perhaps, be better understood from a consideration of the fact that a Mercator track cuts all the meridians *at the same angle;* and since *on the globe* these meridians are *not* parallel to each other, it follows that, to enable this condition to be fulfilled by the ship, she must pursue a circuitous route. The saving in distance is not always the only advantage gained by Great

* For the purpose of actual demonstration on the globe, the distance in this example is rather small. The principle would be better shewn by a similar comparison of the Mercator and Great Circle tracks between Cape Horn and the Cape of Good Hope, or from the latter place to Hobart Town, Tasmania.

Circle sailing. It often happens, in a sailing ship especially, that a foul wind, *according to the Rhumb or straight line course*, is actually a fair one. Hence the advisability of determining the Great Circle course prior to sailing, so that a comparison with the Mercator course can be made, having due regard to the direction and force of the wind.

Take, for instance, the case of a vessel bound from Quebec to Greenock or Liverpool. The true course and distance *by chart* from Belle Isle lighthouse to Inishtrahul lighthouse is N. 83° E., 1,722 miles; but the distance on the Great Circle is 1,690 miles, or 32 less; and the course at starting is N. 63½° E., or 19½° more to the northward. Now, if a sailing-ship, on clearing the Strait, has the wind at E. ½ N., it would at first seem immaterial, on looking at a Mercator chart, which tack she was put upon; but if placed on the starboard tack, she would lie up within 3¼ points of the *true* direction of her port; whilst, if placed on the other tack, instead of approaching her port, *she would be actually going away from it.* **Windward Great Circle sailing.**

The following is a still better example of the advantage gained by Great Circle sailing. It is taken, by permission, from a first-class *practical* Epitome of Navigation, written by the late Captain William C. Bergen, of Sunderland:—

"Given the ship, off Flinders Island, Bass Strait, in lat. 40° 0′ S., long. 148° 30′ E., bound to Callao, in lat. 12° 4′ S., long. 77° 14′ W. It is required to compare the Great Circle and Mercator tracks.

To compare the Courses.

The Mercator course is E. by N. ¾ N., and the first Great Circle course is S.E. ½ E.; the difference, therefore, 4¾ points. Suppose the wind to come from E. by N. ¾ N., that is, right ahead by the Mercator track To a person ignorant of Great Circle sailing, it would appear a matter of indifference, so far as the wind was concerned, on which tack the vessel were put. Suppose one vessel to be put on the starboard tack, and that she could make a course good six points from the wind. Then her course made good would be N. ¾ E., which differs from the Great Circle course 10¾ points, and the vessel would lose 50 miles in the first 100 sailed. **Example from Bergen's Epitome**

Suppose another vessel to be put upon the port tack. Then her course made good would be S.E. ¾ S., that is, within 1¼ points of the first Great Circle course, and she would gain 97 miles in the first 100 sailed.

The two ships sail each 100 miles, and one is 50 miles further from her port than when she started; the other is 97 miles nearer than when she started; thus, in this case, making a difference of 147 miles in less than one day's sail in favour of Great Circle sailing.

Again, suppose the wind to come strong, say half a gale, from the N. ¾ E. Then the vessel on the Mercator track would lie her course, but she would be close-hauled, and it would be necessary to reduce sail in order to ease the vessel, so that she would be forging ahead at the rate of from 1 to 3 miles an hour, and at the same time making from 2 to 4 points leeway; but the vessel on the Great Circle track would have the wind on the quarter, she would carry double-reefed topsails, mainsail, and jib, and would be going at the rate of from 6 to 8 miles an hour.

Again, suppose the wind to increase to a heavy gale from the North, and cause a high sea. Then the ship may run South until the fury of the gale is spent, and she will at the same time gain 63 miles in the first 100 sailed.

* * * * * * * * * * *

To compare the Distances.

The distance by the Mercator track is 7,321 miles, and that by Great Circle is 6,772 miles which therefore is shorter than the Mercator by 549 miles, and it therefore should be adopted, if polar regions, land, shoals, winds, and currents will allow."

Certain occasional advantages of Great Circle sailing.

When these two tracks are at their greatest point of separation they are about 1,500 miles apart, and it will be readily understood that this may mean a very different state of things in regard to winds, weather, and currents. This is strikingly exemplified in the example just given, in which everything is in favour of the Great Circle track.

It is also shewn on the route between Liverpool and Philadelphia. To follow the Great Circle track on this voyage, the vessel must leave by the northern branch of the Irish Channel, which, being shorter than the other, is of course much sooner cleared. The time occupied from land to land by a fast steamship is less than four days, a circumstance in itself very reassuring to passengers, who, when they see Cape Race, consider the dangers of the voyage as practically at an end. The weather is undoubtedly less stormy, though perhaps a trifle colder than that experienced in the trend of the Gulf Stream. Should any cyclonic storms be crossing the Atlantic, the chances are greater for the ship being on their easterly wind side. Fewer vessels are met with, and, consequently, less risk of collision; and lastly, the adverse current of the Gulf Stream is completely dodged by getting inshore of it at Cape Race, from which point, down inside Sable Island, to the Delaware, there is nearly always a favouring current, and much less sea in the North-West gales. Unfortunately this route, from the liability to encounter fog and ice at other seasons, is only safe during the late autumn and winter months.

There are many modes of *calculating* the data for Great Circle tracks, but all are tedious in a measure, and it is very desirable that there should be some graphic method of doing this, so as to enable the navigator to see at a glance whether it is practicable or not; also what winds and currents he may expect by following it. This desideratum has been well supplied by Captain W. C. Bergen, already referred to, who some years ago published a very admirable series of Great Circle track charts. These are so constructed that a *straight line* drawn on them, between any two places, represents the required Great Circle track.*

Bergen's Great Circle Charts.

Once satisfied, by reference to these useful charts, of the advisability of the route thereon indicated, the track should be transferred for greater convenience to a Mercator chart of larger scale; this is usually done by measuring the latitude of the straight line where it is intersected by the various meridians, and pricking off on the working sheet the points thus ascertained. When the meridians are only drawn at every 10th degree of longitude, this is scarcely sufficient for accuracy; in which case the latitude and longitude of the line, at as many intermediate points as may be deemed necessary, should be determined and transferred in the same manner. By connecting these points in pencil, the Great Circle track, as shewn on a Mercator chart, is at once obtained, and that, too, by a very simple operation, which need not occupy more than a few minutes, and is familiar to everyone. A protractor of novel construction is supplied with each chart, for laying off the course at any part of the route; and the instructions for its use are very plain, so that the navigator can please himself as to how he does it.

The principle upon which Captain Bergen has constructed his charts has been fully endorsed by the late Astronomer-Royal, and other eminent mathematicians. For laying down Great Circle tracks, it may be said with confidence that there is nothing half so handy as these charts, and their very low price places them within reach of all.

Another important point in connection with this subject here presents itself. It must not be overlooked that, as the Great Circle track is the shortest possible, there must be another *on its polar side* equal in length to the Mercator track; so that, if from any cause it should be deemed expedient to adopt this last route, or if forced on to it by head winds or obstructions, it is consoling to know that, though to the eye it is *apparently* a terrible round, such is not really the case, or at all events, that it is not more so than the Mercator course.

Track on Polar side of Great Circle

* The United States Hydrographic Office has issued, from time to time, most valuable Great Circle Charts; and No. 90 of its publications, entitled "The Development of Great Circle Sailing," is an admitted classic.

One lesson to be derived from the foregoing is, that when in doubt for the moment as to the tack to go upon with a head wind, no very great harm can be done by putting the vessel on the one which lies *on the polar side of the Mercator course.*

The principle of Great Circle sailing may be made yet plainer by a consideration of the following case. Suppose three very lofty mountains—each 100 miles apart from the other—to be situated in some high latitude, such as Scotland, or Tierra del Fuego; and that an observer on the most *eastern* summit found that all three peaks lay *precisely* in the same straight line; and that the *true bearing* of that line, *as measured from his own meridian,* by careful theodolite observations of the heavenly bodies, was *exactly* West (90°). If this same observer next ascended the most *Western* peak, he would of course find, on looking back, that the three mountains were still in line as before; *but* on taking their *true bearing* from this new position, he would now discover that instead of its being due East—the exact reverse of what he obtained at the first station—it would be about E. 2½° N.* if in Scotland, and E. 2½° S. if in Tierra del Fuego. The explanation is, that each bearing was measured from a different meridian; and as these meridians on the globe do not run parallel to each other, like they are *made* to do in the construction of a Mercator chart, it follows that the true bearings could not possibly be the reverse of each other, as one unlearned in such matters would imagine they ought to be. This accounts for the courses at each end of a long Great Circle track being so very different to each other.

Why the initial courses of a G. C. track are dissimilar.

"Convergency"

In the comparatively short one between Belle Isle and Inishtrahul, the true course at starting from Belle Isle is N. 63½° E.; but the true initial course from Inishtrahul is N. 77° W. On the other hand, the construction of a Mercator chart is such that the true course between any two places is the same at starting as at the finish, or at any intermediate point. In the case just mentioned, it is N. 83° E. in the one direction, and S. 83° W. in the other, or the mean of the two initial Great Circle courses.

To revert to the three mountains: If the observer were a

* Quite a feat was performed in California by the United States Coast Survey. With the aid of an instrument known as the Heliograph, which reflects the sun's rays in the required direction, the reciprocal true bearings of Mount Helena and Mount Shasta were easily obtained, though the observers were 192 miles apart. This is the longest connection of the kind yet made.

The largest triangle in our Ordnance Survey has one angle at Snowdon (3,562 feet above H.W.S.) in Wales, another on Slieve Donard (2,796 feet) in Ireland, and a third at Sca Fell (3,092 feet) in Cumberland. Each side is over 100 miles, and the "spherical excess" is 64."

surveyor, and it was his duty to lay their positions down on a Mercator chart, he would first ascertain very accurately the latitude and longitude of each, and then prick off these positions on the chart.

A Mercator Chart does not shew Objects in their true relative positions.

One not acquainted with chart construction would suppose that, if in nature the mountain peaks existed all in the same straight line, they would do so also on the chart; but it would not be so. If correctly laid down according to their ascertained latitudes and longitudes, they would form a curve, the centre one lying considerably on the polar side of a straight line joining the other two.

This again goes to prove that the Mercator chart depicts falsely the geographical features of the earth, but here disparagement ends, for of all the known projections it is the one best suited to the *general* requirements of the navigator.

By Bergen's charts, COMPOSITE Great Circle sailing is rendered quite simple; they have, moreover, the advantage of shewing at once whether the preference should be given to it or to the strict Great Circle. A pamphlet containing a full explanation of the different applications of Great Circle sailing accompanies each chart.

In the chapter entitled "Sky Pilotage," an effort is made to engraft upon the mind of the reader that an *Azimuth Circle* is a *Great Circle*, but as the chapter in question was getting spun out rather more than seemed desirable, it was left to the present one to give a practical and convincing proof of the truth of the statement, and to shew how advantage may be taken of it.

Great Circle courses found by Burdwood's Tables.

Open Burdwood's Tables at page 305, and ascertain therefrom the sun's *true azimuth* with following data:—Lat. of ship 60° N., Declin. 23° N. App. time at ship, 5 hrs. 48 m. P.M. The answer is N. 80° 31′ W.

Next, ignoring winds, currents, and intervening land, ascertain the initial *Great Circle Course* between Bergen in Norway (lat. 60° N., long. 5° E.) and Havana (23° N., 82° W.), so famous for the soothing weed of Cuba. You can do this by any method you like best, and, in passing, it may be said that there are no end of ways. If you work correctly, the answer will be N. 80½° W., or identically the same as the *sun's true Azimuth* in the preceding half of the experiment.

Therefore, to find Great Circle courses by the Azimuth Tables you have only to regard the Latitude of the port *bound to* as Declination, and the difference of Longitude, turned into time, as the hour angle. The latitude of ship you take from the top of the page as usual.

It will be noticed in this example that the difference of Longitude between Bergen and Havana is 87°, equal to 5 hrs. 48 m.

A voyage from Bergen to Havana.

This is a "Wrinkle" worth knowing, as it very much simplifies the determination of G. C. courses, and, seeing the number of Tables and other contrivances* now published for expeditiously finding the true azimuth, it makes the whole business "as easy as falling off a log."

But we have not yet quite done with this interesting problem. The distance by G. C. sailing is 4,125 miles, and by Mercator sailing it is 4,340; the difference (215 m.) is not much in so long a run, but the difference in the initial course ($40\frac{1}{4}$°) is remarkable, and, as it so happens, it lies on the side the navigator would prefer to have it. For example, the initial G. C. course (N. $80\frac{1}{2}$° W.) takes right out into open water to the northward of the Shetland Isles, whereas the Mercator course (S. $59\frac{1}{4}$° W.) would require the passage to be taken between the Shetland and Orkney Isles, perhaps on a dark night, and in the teeth of a "dirty South-wester."

To impress this thoroughly: let it be understood that if a vessel sailed from Bergen and adopted the Mercator course, the man at the masthead, *if he could see Havana*, would report it as nearly $3\frac{3}{4}$ points on the starboard bow, and having signed articles for a voyage to the West Indies and back, would wonder where on earth the 'Old Man' was steering to.

A voyage from Bergen to Quebec.

Now, as G. C. sailing is principally of use between places of high latitudes, Burdwood's Tables—giving the declination only to 23°—are not really of much good, and a voyage (Bergen to Havana) had to be contrived that would suit them. This being so, we must cast about for something better, and in "Lecky's A B C Tables" we have it. All you have to do is to select in Table B a star with a declination near about equal to the latitude of the port bound to; whether they are of the same name or otherwise does not signify a jot, as will be shewn.

This time let the voyage be from Bergen to Quebec, and let it be intended to enter the Strait by the passage between Belle Isle and Labrador. The point aimed at would consequently be

* A masterly description of almost every possible method, with explanatory diagrams, will be found in No. 90 of the valuable aids to navigation published by the United States Hydrographic Office. It is entitled the *Development of Great Circle Sailing*; and compiled by Mr. G. W. Littlehales, of that office.

in $52\frac{1}{2}°$ N., 55° W. Looking in the list for a star with about this declination, we find *Canopus* registered as 52°·6 S., which is 'the very medicine the Doctor ordered.'

Referring to bottom portion of Table B (page 441), we find *Canopus* ready to hand. Now, Bergen is in 5° E., so the difference of longitude is 60°, equal *in time* to 4 hrs. 0 m. **Bergen to Quebec.**

The problem then takes this form:—

Being at Bergen in 60° N., what is the true azimuth of *Canopus*, supposing its declination to be *North*, at 4 hrs. 0 m. West of the meridian?

Table A, Lat. 60°		+ 1·000
" B, *Canopus*		− 1·512
		− 0·512

Enter Table C with Lat. 60°, and at sight the true azimuth corresponding to ·512 is found to be $75\frac{3}{4}°$. By the rule at the bottom, it is to be named N. and W. The figures are but few, and the whole operation need not take three minutes. Next, work out (if you know how) the G. C. course from Bergen to Belle Isle (lat. 60° N., long. 5° E., to lat. $52\frac{1}{2}°$ N., long. 55° W.) and it will be found *identical* with above, namely, N. $75\frac{3}{4}°$ W.

N. $75\frac{3}{4}°$ W.

Thus "Lecky's A B C Tables" afford an easy method of working G. C. courses.*

To reverse the process, or find the initial course from Belle Isle to Bergen: this time you must select a star in Table B, with a Declination of 60°, corresponding with the Latitude of Bergen. Remember, the star must always represent the port *bound to.* *β Centauri* just suits:— **Quebec to Bergen.**

Table A, Lat. $52\frac{1}{2}°$	- (page 440) -	+ 0·752
" B, *β Centauri*	- (" 441) -	− 1·991
		− 1·239

In Table C (page 449), with Latitude $52\frac{1}{2}°$, the azimuth will be found N. $52\frac{3}{4}°$ E., which is the *first* course to steer on leaving Belle Isle. The distance between the two given positions is $1,976\frac{1}{4}$ miles. The distance, however, is of much less importance—it is constant for a full-powered steamer; but the course is constantly altering, and demands an expeditious way of finding it.†

The Epitome methods of working G. C. courses and distances

* See important article, page 1093 of *Naut. Mag.* for December, 1895; and *Navigation*, by D. Wilson-Barker and W. Allingham, pages 147-150 (Messrs. Griffin & Co., London).

† In the enlarged Tables, published separately, the Declination is carried to 65°; consequently, Great Circle problems in high latitudes can be solved without recourse to the stellar portion of Table B.

are no doubt rigorously accurate, but they are dreadfully tedious and complicated, and the A B C Tables will be found a most convenient substitute. It will now be shewn how they can be conjured into giving Great Circle Distances as well as Courses.

Rule for the Distance.

1. Consider the "True Azimuth" head-line in Table C to represent the difference of Longitude between the two places. Then enter left-hand column with Latitude of *place of departure*, abreast this, and, under the degrees taken as representing the difference of Longitude, take out the tabular value. Prefix the sign + or – according to whether the difference of Longitude is less or more than 90°.

Note.—When it exceeds 90° you must use its supplement

2. Convert the Initial Course into Time. Then enter left-hand column of Table A with Latitude of *place of departure* as before, abreast this, and, under the hours and minutes representing the Initial Course, take out the tabular value. Prefix the sign + or – according to whether the course is reckoned from the elevated or depressed pole.

3. Add together algebraically the two values found as above.

4. Enter the Latitude column of Table C with the *complement* of the Initial Course; and, on the line abreast, seek out the value agreeing with the sum of those referred to in precept No. 3. Over this value, in the head-line marked "True Azimuth," will be found the degrees giving the approximate Great Circle Distance. By interpolation it can obviously be taken out to parts of a degree.

Although the method is correct, great accuracy cannot reasonably be expected *without careful interpolation.* Multiply by 60 for miles.

Taking the Bergen-Quebec example, we have

Table C.	Latitude 60°, and diff. of Longitude 60° - -	+ 1·155
Table A.	Latitude 60°, and Course 75¾° = 5 hrs. 3 m. -	+ ·440
		+ 1·595

Table C. With 1·595 and 14¼° (compl. of Initial Course) the distance is 32° 54′ = 1,974 miles.

By way of emphasizing the utility of the A B C Tables, let us now take the Bergen-Havana example for Distance.

Table C.	Latitude 60°, and diff. of Longitude 87° - -	+ 0·105
Table A.	Latitude 60°, and Course 80½° = 5 hrs. 22 m.	+ 0·289
		+ 0·394

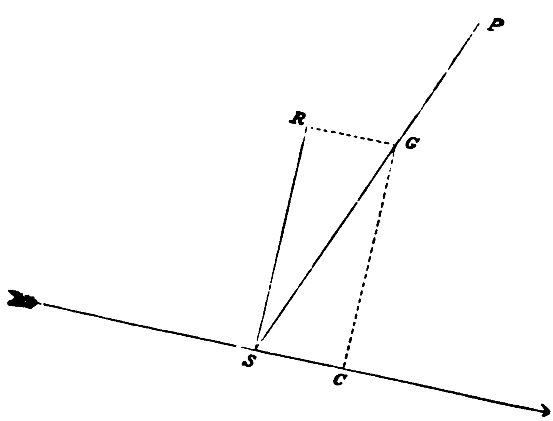
Table C. With 0·394 and 9½° (compl. of Initial Course) the Distance is 68° 47′ = 4,127 miles, which is not far from the truth.

But all this is somewhat of a digression, and we must return to the subject which has given a title to this chapter.

To allow for a known current or tide when shaping a course, is only an application of the "Composition of Velocities." In the parallelogram *RGSC*, the direction *SR*, in which the ship is steered, gives one component; the direction of the current *SC* is another; and the course made good, *SG*, is the resultant.

Let *P*, the port, bear N. 35° E. from *S*, the ship, whose rate of sailing is 8 miles per hour: let the arrow represent the *direction* of a 3-knot current setting S. 77° E. From *S* lay off on the arrow the hourly drift *SC*, taking the measurement from any convenient scale, say half an inch to the mile. Using the same scale, take in the dividers the vessel's hourly speed; and placing one foot at *C*, the other will fall upon the line *SP* at the point *G*. Draw the dotted line *GC*, and rule *SR* parallel to it; also dot *RG* parallel to *SC*. The Parallelogram is now complete, and its opposite sides are equal to each other.

Current Sailing.



By steering in the direction SR = N. 14° E., the vessel will

Current Sailing.

make good her intended course *SP*, and keep the port all the time on the same line of bearing. So long as the angle *GSC* is *less* than the angle *GCS*, the current is favouring the vessel—in the present case to the extent of half a mile an hour. The figure need not necessarily be drawn on the *face* of the chart; the *back*, or any spare piece of paper, will do equally well; and the scale may be anything that is desired. Should the chart scale be employed, it will generally be necessary to multiply the vessel's speed and the drift of the current by some convenient factor—say 5—so as to get a good working size for drawing the figure. If 5 be used, the side *CG* will equal 40 of the chart scale, and the side *SC* will equal 15 of the chart scale. A protractor, or Field's parallel ruler, can be used for laying off the angles.

From a consideration of the diagram it will be readily seen that a fast vessel in channel, when running between any two points, is not so much influenced by tide as a slow one.

Leeway, and heave of the Sea.

In making up the reckoning, leeway and heave of the sea must be allowed for *according to judgment*, as they vary in different vessels according to their build; and in the same vessel according to her draught and trim for the time being. They depend also upon the amount of wind and sea, and the sail carried, so that no fixed rule for estimating them can be laid down. The leeway table one usually sees in books on Navigation is therefore but of little value.

"Sail" your vessel if sea will permit.

There is, however, a somewhat important matter to be considered in connection with leeway. Suppose a vessel, on a wind heading N.W. by N., under short canvas, and looking up within 3 points of her port, which accordingly bears north; but, owing to its blowing hard, she is making 2½ points leeway. Clearly this vessel is only *making good* a N.W. by W. ½ W. course, which is 5½ points from the direction of her port. Let her speed under these conditions be, say, 4 knots. Now, if the yards be checked in a point or so, and the vessel be kept off N.W. by W., she will slip away much faster through the water, and probably will make not more than half a point leeway. This keeps the course *made good* exactly the same as before, with the advantage of increased speed. Therefore, if you can possibly avoid it, do not allow your vessel to sag to leeward by jamming her up in the wind. KEEP YOUR WAKE RIGHT ASTERN, unless it be found from the bearing of the port that the course *made good* is actually taking the vessel away from it, in which case it is obvious that the less the speed the better.

In Steamers it is often a matter for consideration whether, by keeping away in a head wind, and setting fore-and-aft canvas, the increased speed will compensate for the extra distance sailed over. It may be accepted as a fact that, by keeping away in full-powered steamships, there is no advantage gained under *ordinary* conditions of wind and sea. Generally, now-a-days, the sails of large steamers are so disproportionate to the size of hull, that their *propelling* effect is but trifling, though their *steadying* effect may be considerable.

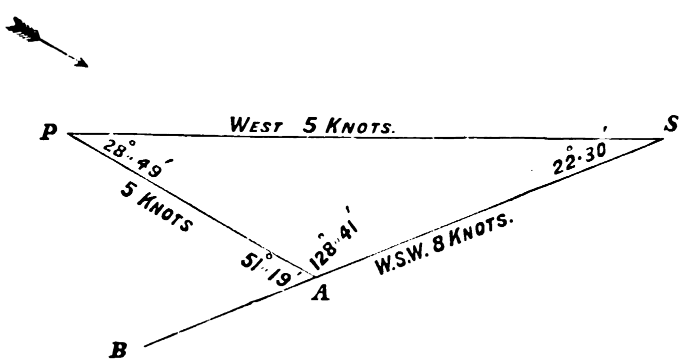
Expediency of keeping a Steamer away in strong Head Wind.

When blowing a gale, however, with a heavy head sea smothering everything fore and aft, it is probably advantageous to ease a fast steamer by keeping off sufficiently to get the fore-and-afters to stand with the booms nearly amidships. By this means she would take the sea more kindly, and the canvas would keep her side down; but she would probably lose in the matter of nearing her port. On the other hand, in an under-powered boat of small or moderate size, it would undoubtedly be a gain to assist her with canvas. Against a strong wind and head sea such vessels will do absolutely next to nothing. In addition to want of power, their propellers are too near the broken surface water; and, being short vessels, they "race" heavily in a head sea, which necessitates shutting off steam just at the time it is most required.

In the long, deep-draught vessels of the trans-Atlantic lines, pitching is reduced to a minimum, and the screw, from being well immersed, has a good grip of the water, and is better able to stand up to its work. This is particularly the case in twin-screws, owing to their smaller diameter.

When a steamer is thus kept away under sail, and a port is not far distant, a point will be reached when, to avoid losing ground, it will be necessary to haul up and steer directly for it. Seafarers are indebted to Captain W. B. Duncan, formerly of the Marine School, South Shields, for the investigation of

Triangular Sailing.



Triangular Sailing.

the rule for what he proposes to call "Triangular Sailing." By permission it is here inserted, nearly verbatim, from *Bergen's Epitome.*

In the above figure, let S be the ship's place, P her port; let the arrow denote the direction of the wind, PSA the angle that the ship must be kept away in order that the sails may pull; A the place where the ship must be hauled up direct to her port; AP its bearing at that time; and let the rate of speed in the direction SP, SA, and AP, be respectively 5, 8, and 5 miles an hour; then we have the following

RULE.

Put the rates of sailing in the form of a vulgar fraction, of which the numerator is the lesser rate, and the denominator the greater rate;* reduce this fraction to a decimal, find the angle of which this decimal is the natural cosine. It will be the angle PAB between the ship's track, SAB when she is kept away, and the bearing of the port AP at the time she ought to be hauled up for it.

Taking the preceding rates, we have by the rule $\frac{5}{8}$ = ·625000, which is the natural cosine of 51° 19′, that is, 4½ points, roughly. Let the ship be on the starboard tack, and her course SAB when kept away W.S.W.; then N.W. by W. ½ W. is 4½ points from W.S.W., and is therefore the bearing of the port when the ship is hauled up for it.

TO FIND THE POINT A ON THE CHART.

Through S, the ship's place, draw SAB, to represent the course W.S.W.; and through P, the port, draw PA, the bearing N.W. by W. ½ W. The point where these two lines intersect will determine A. The distances SA and AP can then be measured, and the time of going these distances compared with the time of going the distance SP.

BY CALCULATION.

Referring to the figure: In the triangle APS, let SP = 100 miles; then, by Trigonometry,

$$SA : SP :: \text{sine } P : \text{sine } A.$$
$$AP : SP :: \text{sine } S : \text{sine } A.$$

* "A *Fraction* is a quantity which represents a part or parts of an integer or whole. A *Vulgar* (that is, a common) fraction, in its simplest form, is expressed by means of two numbers placed one over the other, with a line between them. The lower of these is called the *Denominator*, and shews into how many of equal parts the whole is divided; the upper is called the *Numerator*, and shews how many of those parts are taken to form the fraction. Thus, $\frac{3}{4}$ denotes that the whole is divided into four equal parts, and that three of them are taken to form the fraction."—COLENSO.

Let the angle $S=2$ points ; then the angle $A = PAS = 180° - PAB - 180° - 51° 19' = 128° 41'$. Triangular Sailing.

And the angle $P = 180° - (A + S) = 180° - (128° 41' + 22° 30') = 28° 49'$.

Hence we have as follows:—

To Find SA.

Angle P 28° 49′	Sine	9·683055
Angle PAB 51° 19′	Cosec.	0·107565
SP 100′	Log.	2·000000
SA 61′·75 . . .	Log.	1·790620

To Find AP.

Angle S 22° 30′	Sine	9·582840
Angle PAB 51° 19′	Cosec.	0·107565
SP 100′	Log.	2·000000
AP 49′·02 . . .	Log.	1·690105

To find the Time saved.

MILES.	KNOTS.	HOURS.
SA 61·75 ÷ 8 =		7·72
AP 49·02 ÷ 5 =		9·80
		17·52
SP 100 ÷ 5 =		20·00
Time saved =		2·48 that is, nearly 12½ per cent.

Notes.—(1) If a change of wind occur, the chances that it will be in favour of the vessel are as 16 to 3. (2) If the wind be blowing so hard that a small-powered vessel cannot steam against it, tack her when the port is right abeam.

In these days of "Steam" there need be no apology for introducing the question of Coal Consumption. It is a subject which has a very practical aspect for both Owner and Master. It affects the pocket of the one, and the reputation of the other. The tail-end of a chapter on "Shaping the Course" seems the natural place to deal with it.

The master of every steamer—at least of every foreign-going steamer—should be able to calculate fully as well as his Engineer-officers the distance a certain quantity of coal will take him at any given speed: or, putting it the other way about, he should know what reduction to make in his speed to enable him to steam a given distance with the coal at his disposal. What the Master should know.

It is obvious that this is a matter of the very first importance, nevertheless there are astonishingly few men who understand the principle involved in the problem or can figure it out. This surely cannot be due to any difficulty in the way, because, as will presently appear, the solution is as simple as it well can be. Nor can it arise from an idea that, in the event of coal running short, the Chief Engineer would have to bear the brunt of the blame; for this would be simply a weak and unworthy attempt to shirk the responsibility properly attaching to his own position as master. There must be some other explanation, but what it is the writer does not know.

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To Find *SA*.			To Find *AP*.		
Angle P 28° 49′	Sine	9·683055	Angle S 22° 30′	Sine	9·582840
Angle PAB 51° 19′	Cosec.	0·107565	Angle PAB 51° 19′	Cosec.	0·107565
SP 100′	Log.	2·000000	SP 100′	Log.	2·000000
SA 61′·75	Log.	1·790620	AP 49′·02	Log.	1·690105

To find the Time saved.

Miles.	Knots.	Hours.
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AP 49·02	÷ 5 =	9·80
		17·52
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Consumption in relation to speed.

"Knowledge is Power." There is no truer saying, and if the Master wishes to *be* Master, and to *continue* Master, he should know all about coal consumption, and much more besides in the same direction. Ignorance of such a very rudimentary matter necessarily places the so-called Master in the hands of subordinates, and is calculated to bring the profession into well-merited contempt. He must not wonder or complain if occasionally some are found to take advantage of his weakness. The Colonel of a regiment should know to a fraction how far his men can march under given conditions, and what rations he has available to keep them going. In the event of break-down on the road it would be a lame excuse to say that he relied upon the Doctor to tell him about the first, and the Commissariat officer as to the last. Why did the Board of Trade institute examinations in steam for Navigating officers? Because evidently it was considered advisable that those in supreme control should have *some* knowledge of that which they controlled. They can never hope to be Experts: life is not long enough. Neither can the Engineer rightly hope to be a Navigator: he may be one or other, as choice dictates, but not both. Each has plenty to do in his own sphere; some say, too much.

With this dissertation respecting one of the many responsibilities of a Ship-Master, we will pass on to the solution of the main question. When the Builder delivers a new steamer, it is customary to tell the Owner her capabilities in various directions, such as measurement and dead-weight capacity, stability, speed, &c. Some Builders give much more complete information than others, but in relation to coal consumption the following should always be forthcoming.

Data to be supplied to Master.

1. Speed on trial-trip, accurately determined.
2. Corresponding Indicated Horse Power.
3. Corresponding revolutions.
4. Corresponding draft of water.
5. Pitch and Slip of Propeller.

Consumption of "Triples" and "Compounds."

Also, the same data (calculated) for ship when down to her load marks. Now, well designed "Triples" should not burn *more* than 1·7 lbs. of good South Wales coal per Indicated Horse Power; but to be on the safe side we will put it at 1·8 lbs.; for coal is not *always* of the best, boilers *will* occasionally leak, tube-stoppers are not unknown, and altogether there are a number of things that tend to run up the consumption. In like manner, compound engines in ordinary working may be taken to burn as much as 2·2 lbs., so that, knowing the I.H.P. of a set of engines, it is easy to calculate what they will burn at full speed. We have therefore arrived at the fact that Power and Fuel are convertible terms.

The question, as narrowed down, is now as follows :—

Supposing a vessel is found to have insufficient coal on board to reach her destination at full speed, to what should she slow down to make sure of getting there in reasonable time? The rule is that *the Indicated Horse Power* (*or coal consumption*) *varies with the cube of the speed of the engines.* As usually stated, the last three words are omitted, leaving it indefinite as to whether the speed of the engines or of the ship is meant, and, as we shall presently see, there may be a vast difference in the result.

Proper way to state the rule.

Taking the case of the ss. *Highflyer*, indicating 4356 H.P., at 153 revolutions, with a corresponding speed in *fine weather* of 20 knots; the consumption, at 1·8 lbs., would be just 3·5 tons per hour.

This example will be worked both with speed of ship and speed of engines. All conditions being favourable, there will be no difference, but in bad weather, with a foul bottom, or with increased immersion, it will be considerable. Judgment and experience are required to deal with what occurs in practice.

EXAMPLE.

If 3·5 tons of coal per hour be required for a speed of 20 knots in a moderate breeze and smooth sea, how much is required for a speed of 10 knots under similar conditions?

$20^3 : 10^3 :: 3{\cdot}5$ tons. Answer 0·4375 tons = 8 cwt. 3 qrs.

20 knots	10 knots
× 20	× 10
400	100
× 20	× 10
8000	1000
	× 3·5 tons
	5000
	3000

Tons

8000) 3500·0 (0·4375
3200·0

30000
24000

60000
56000

40000
40000

$$\begin{array}{r} \text{Tons } 0\cdot4375 \\ \times\ 20 \\ \hline \text{cwt. } 8\cdot7500 \\ 4 \\ \hline \text{qrs. } 3\cdot0000 \\ \hline\hline \end{array}$$

Of course no one would dream of working out the cubes as on opposite page when they can be taken out at sight from almost any engineer's pocket-book. *Mackrow's Naval Architect's and Shipbuilder's Pocket-book* gives the squares and cubes of numbers up to 2,201, and there are many others that do pretty much the same. But supposing none of these Tables available, calculation *must* be resorted to, and where decimals happen to come in, the rows of figures become formidable; then the easiest way is by logarithms.

A useful book.

Multiplication by logs. is done by addition, and division is done by subtraction; and to raise a number to any power (Involution), you merely multiply the log. of the number by the index of the power required; thus:—

EXAMPLE I. (REPEATED).

$20^3 : 10^3 :: 3\cdot5 :$ Result

$\therefore$ Result $= (10^3 \times 3\cdot5) \div 20^3$

$\therefore$ Log. Result $= 3$ Log. $10 +$ Log. $3.5 - 3$ Log. 20

$$\begin{array}{lr} 3 \text{ Log. } 10 & 3\cdot0000 \\ \text{Log. } 3\cdot5 & 0\cdot5441 \\ \hline & 3\cdot5441 \\ 3 \text{ Log. } 20 & 3\cdot9031 \\ \hline 0\cdot4375 \text{ Log.} & \bar{1}\cdot6410 \\ \hline\hline \end{array}$$

$\therefore$ 0·4375 tons = 8 cwt. 3 qrs. is required for speed of 10 knots.

A useful fact.

It looks almost incredible that less than half a ton per hour should suffice for 10 knots, when it takes 3½ tons in the same vessel to get 20 knots; but "it is the last straw which breaks the camel's back," and it is the last half knot that swallows the coal.

We will now try the same problem, substituting revolutions of engines for speed of ship. Assuming, for the moment, the "slip" to be the same in each case, a simple proportion sum shews that 76½ revolutions would be required for 10 knots. Then we have—

$153^3 : 76{\cdot}5^3 :: 3{\cdot}5 :$ Result	3 Log. 76·5	5·6510
	Log. 3·5	0·5441
$\therefore$ Result $= (76{\cdot}5^3 \times 3{\cdot}5) \div 153^3$		
		6·1951
	3 Log. 153	6·5541
$\therefore$ Log. Result = 3 Log. 76·5 + Log. 3·5		
− 3 Log. 153	0·4375 Log.	$\bar{1}{\cdot}6410$

$\therefore$ 0·4375 tons is required as in previous example.

Speed of ship is one thing; speed of engines is another.

We now come to the reason for substituting speed of *engines* for speed of *ship*. If the speed of the *Highflyer* in smooth water be 20 knots with 153 revolutions, the same number would *not* give the same speed in heavy weather: that is a dead certainty, as everyone is aware. The speed might possibly drop to 10 knots, but so long as the full number of revolutions was maintained, the maximum consumption of 3·5 tons would *also* be maintained; shewing that *speed of the ship* cannot always be taken as a guide in the matter of consumption. It is preferable to take the *speed of the engines*, for upon the revolutions depends the Indicated Horse Power, and upon the Indicated Horse Power depends the coal consumption.

We will now invert the foregoing example, thus:—

If 153 revolutions can be got with an expenditure of 3·5 tons, what number can be got with an expenditure of 0·4375 tons?

$3{\cdot}5 : 0{\cdot}4375 :: 153^3 :$ Result^3	Log. 0·4375	$\bar{1}{\cdot}6410$
	3 Log. 153	6·5541
$\therefore$ Result$^3 = (0{\cdot}4375 \times 153^3) \div 3{\cdot}5$		
		6·1951
	Log. 3.5	0·5441
$\therefore$ 3 Log. Result = Log. 0·4375 +		
3 Log. 153 − Log. 3·5	3 Log. Result	5·6510
	Log. Result	1·8837

$\therefore$ Revolutions to be got = 76·5.

"Slip."

Explanation of "Slip."

Consumption and speed naturally lead up to the question of "Slip." In the *Highflyer* the pitch of the propeller is 14·6 feet. But what is meant by "Pitch"? It may be explained briefly as follows: If the propeller revolved in a fixed solid—like a cork-screw in a cork—the distance it would move forward in one complete revolution would be the "Pitch." But water, not being a fixed solid, yields to the push of the propeller; the loss arising from this is the *apparent* slip, and it may be described as the difference between the speed of the ship and the speed of the propeller. With correct data to go upon, the slip is easily calculated. For example:—

To find "Slip."

The *Highflyer* has a propeller with a pitch of 14·6 feet, and at 153 revolutions she is found by trials in slack water to have a speed of 20 knots. What is the amount of slip, and its percentage?

Pitch - - 14·6
Revolutions - 153

438
730
146

2233·8 speed of propeller per minute in feet.
× 60 minutes

134028·0 speed of propeller per hour in feet.

Feet in a mile 6080) 134028·0 (22·04 speed of propeller in knots.
12160 20·00 speed of ship ,,

12428 2·04 = Slip.
12160

26800
24320

To find *per centage* of "Slip."

To find the *percentage* of slip proceed as under.

As 22·04 knots : 100 knots : : 2·04 slip : Answer.

2·04

400
2000

22·04) 204·00 (9·25 per cent. slip.
19836

5640
4408

12320
11020

Inverting the question we get the following:—

Pitch 14·6 ft., Revolutions 153, Slip 9·25 per cent. Required the speed of the ship?

Knots.

$14 \cdot 6 \times 153 \times 60 \div 6080 = 22 \cdot 04$ = speed of propeller.

Then as 100 : 9·25 : : 22·04

```
                  22·04
                   9·25
                  -----
                  11020
                  4408
                19836
100 ) 203·8700 ( 2·04 Slip.
      200
      ---
        387
        400 nearly.
```

Speed of propeller - -	22·04 knots per hour.
Slip - - - - -	2·04 „ „
Speed of ship - - -	20·00 „ „

It will be noticed that the percentage is calculated on the speed of *the propeller,* not of the ship.

EXAMPLE.

Owing to heavy head wind and sea, the speed of the ship has fallen off to 10 knots, though the revolutions are still maintained at 153. Required the percentage of slip. **Exaggerated instance.**

Speed of propeller.........	22·04 knots.
Speed of ship	10·00 „
Slip.........	12·04 „

As 22·04 knots : 100 knots : : 12·04 slip.

```
                   12·04 slip.
                   × 100
22·04 ) 1204·00 ( 54·6 per cent. slip.
        11020
        -----
         10200
          8816
         -----
         13840
         13224
```

The percentage of slip is, of course, entered daily in the Engine-room Register, along with a host of other useful items for the Master to consider, and to utilize in the navigation of his ship.

In this little matter of making the coal spin out, it has been made clear that weather is a factor in the calculation that cannot be neglected; therefore, so arrange your speed as to leave a margin for eventualities. If you think you can fetch at 8 knots, better slow down to 7, at all events for the first half of the distance. **Professional perplexities.**

We will now look at another phase of this all important question of fuel consumption.

RULE.—*The consumption varies as the square of the speed multiplied by the distance.*

Let consumption be C when speed is S and distance is D, and
Let consumption be c when speed is s and distance is d; then we have the following proportion:—

$$C : c :: S^2 \times D : s^2 \times d.$$

EXAMPLE.

If 121 tons of coal suffice for 1134 miles at a reduced speed of 10 knots, how many tons will suffice for 1522 miles at 12 knots under similar conditions of wind and sea?

Let C = required quantity, c = 121 tons, S = 12 knots, D = 1522 miles s = 10 knots, d = 1134 miles. Then we have—

$C : c :: S^2 \times D : s^2 \times d$; or $C : 121 :: 12^2 \times 1522 : 10^2 \times 1134$.
Log. C = (log. c + 2 log. S + log. D) − (2 log. s + log. d).

log. c	2·08279		
2 log. S	2·15836		Hence C = 234; and coals
log. D	3·18241	7·42356	required will be 234 tons.
2 log. s	2·00000		
log. d	3·05461	5·05461	
log. C		2·36895	

The wording of the question may be altered thus:—

A steamer having made a voyage of 1134 miles at a reduced speed of 10 knots, with a total expenditure of 121 tons of fuel, what should be her consumption for a voyage of 1522 miles at 12 knots, the weather and other conditions being the same? *Answer:* 234 tons.

The following is another variety of the problem. The last rule still holds good.

Example.

A steamer is supplied with fuel sufficient for 2000 miles at a speed of 10 knots; at what reduced speed must she steam to cover 3000 miles? Let s = reduced speed, then

$$C : c :: 2000 \times 10^2 : 3000\, s^2.$$

But C and c are now equal.

$$\therefore 2000 \times 10^2 = 3000\, s^2$$
$$3\, s^2 = 200$$
$$s^2 = 66 \cdot 6$$
$$s = 8 \cdot 16 \text{ knots.}$$

or:—

Multiply the original distance by the square of the original speed, and divide by the new distance. Then the square root of the product will be the required speed.

Keeping to the same example, we have original distance. D = 2000 miles, the original speed S = 10 knots, and the new distance d = 3000 miles, to find the corresponding reduced speed s. Then formula becomes:—

$$d : D :: S^2 : s^2$$
$$\therefore s^2 = (D \times S^2) \div d$$
$$\therefore 2 \log. s = \log. D + 2 \log. S - \log. d$$

log. D	3·30103
2 log. S	2·00000
	5·30103
log. d	3·47712
2 log. s	1·82391
∴ log. s	0·91195

Hence s = 8·165; and the reduced speed is 8·165 knots.

Obtaining the square root, or the cube root, in the usual way is rather a puzzle to many outside the four walls of a school; but logarithms do away with all doubt if we remember that the log. of the square root of a quantity is half the logarithm of the quantity itself; and the log. of the cube root of a quantity is one-third the logarithm of the quantity itself.

One more example will suffice to show this.

A steamer has accomplished 1200 miles at 10 knots, with an expenditure of 140 tons of coal; she has got 1400 miles to go, but the engineer reports he has only 100 tons left to do it with. At what reduced speed must she now steam to fetch her destination? Then the formula is:—

$$C : c :: S^2 \times D : s^2 \times d.$$

$$\therefore s^2 = (c \times S^2 \times D) \div (C \times d)$$

$$\therefore 2 \log. s = (\log. c + 2 \log. S + \log. D) - (\log. C + \log d)$$

log. c	2·00000	
2 log. S	2·00000	
log. D	3·07918	7·07918
log. C	2·14613	
log. d	3·14613	5·29226
2 log. s		1·78692
∴ log. s		0·89346

Hence $s = 7·825$; and the reduced speed is 7·825 knots. Therefore slow down to $7\frac{1}{2}$ knots to be on the sure side.

This is what Captain D. Wilson-Barker, R.N.R., F.R.S.E., of the Thames Nautical College, H.M.S. *Worcester*, would call "steamanship"—a necessary accomplishment in these days.

CHAPTER XVIII.

THE DANGER ANGLE, AND CORRECT DETERMINATION OF DISTANCE FROM LAND.

Acquaintance with height of the eye useful in estimating Distance.

As laid down in a previous chapter, every captain and officer on board ship should keep a note of the height of the eye above the load-line corresponding to the bridge, upper, and main decks. If this be known for any given draught, it is, of course, easily ascertained for any other. Such information is useful, not only for the correct application of the "Dip" in every-day sight-taking, but it is of importance in arriving at the approximate distance from a beacon light when it first pops into view above the horizon in clear weather.* It also affords a ready means of estimating by eye alone the distance of an object, by referring its water-line to the sea horizon.

"Dip."

The distance of the visible horizon depends mainly upon two things, namely, the curvature of the earth's surface, which may be assumed as constant, and the height of the observer's eye, which, of course, varies with circumstances; and this distance happens to correspond *approximately* to the square root of the height of the eye, "an accidental relation"—as Raper puts it—"easy to remember." Thus, if the height of the eye be 25 feet, the distance of the visible sea horizon will be *about* 5 nautical miles: if the height of the eye be 36 feet, the distance will be *about* 6 miles, and so on. (For "Dip" *see* page 323 and Appendix (N).

Distance of the visible Horizon.

To get a still closer approximation, multiply the square root of the height in feet by 1·063.

The general tendency, however, of terrestrial refraction is to throw up the horizon, and slightly increase the distances thus obtained; therefore, when some degree of accuracy is aimed at, you must use 1·15 as a factor instead of 1·063. Refraction in-

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* By Beacon light is meant any one of the various coast lights exhibited for purposes of navigation.

creases the distance of visibility on the average by 8% of the intercepted arc, hence the difference in the factors.

If an observer, whose eye is elevated say 20 feet above the sea level, is passing a small island, rock, ship, or other object, whose *water-line* appears one unbroken continuation of the sea horizon, he knows that his distance from it is rather more than 5 miles. If the water-line of the object appears *nearer* to him than the horizon, he knows that the distance must be *less* than 5 miles; and if the water-line is invisible, and consequently *beyond* the horizon, he knows it must be *greater* than 5 miles. Indeed, by ascending or descending till the water-line of the object comes on a new horizon, corresponding to the altered level, it is possible to make a very fair shot at the actual distance.

Distance from Beacon Light.

Similarly, in clear weather, when a beacon light first shows itself above the horizon, the *approximate* distance from it may be found as follows:—take the square root of the elevation of the observer's eye, and the square root of the elevation of the light, both in feet. Add them together, and you have the distance required. Let the eye, for example, be 16, and the light 169 feet above the sea level. The square root of 16 is 4, which, added to 13, the square root of 169, gives 17 nautical miles as the approximate distance of the light when first sighted.* *(Do not forget to note the time. The greater the speed of your ship the more necessary is this caution).*

The following table, in which refraction is taken into account, gives a still closer approximation. In the case just quoted it makes the distance 19½ miles instead of only 17.

On this account, and being easy of reference, it is preferable to cudgelling one's brains over the extraction of square roots. It is taken from the Author's *Danger Angle, and Off-shore Distance Tables.*

* What is here stated refers only to such lights (1st and 2nd order) as have sufficient power to be seen at distances corresponding to their elevation. It is necessary to discriminate between the *Luminous* range and the *Geographical* range; the one depends upon the power of the light, and the other upon its elevation. For example, the light on San Lorenzo Island, Callao, had the absurd elevation of 980 feet, which should give it a range of 41 miles, but it was such a poor affair (1880) that 10 or 12 miles was about its outside limit of visibility. On account of greater liability to obscuration by fog or mist hanging over hill-tops, 200 feet should be the maximum elevation for beacon lights, but peculiarities of position sometimes *force* engineers to place them higher. San Lorenzo Light was discontinued in 1897, and a new light established on Palominos Rocks. (*See* Light List, Part VII., No. 242.)

Table of maximum distance at which an object is visible at sea according to its elevation and that of the observer, the weather being clear and the refraction normal.

Heights.	Distance of sea horizon.	Heights.	Distance of sea horizon.	Heights.	Distance of sea horizon.	Heights.	Distance of sea horizon.	Heights.	Distance of sea horizon.	Heights.	Distance of sea horizon.
Feet.	Naut. miles.	Feet.	Naut. miles.	Feet.	Naut. miles.	Feet.	Naut. miles.	Feet.	Naut. miles.	Feet.	Naut. miles.
1	1·15	35	6·81	69	9·55	115	12·34	285	19·41	510	25·97
2	1·63	36	6·90	70	9·62	120	12·60	290	19·57	520	26·22
3	1·99	37	7·00	71	9·69	125	12·86	295	19·75	530	26·47
4	2·30	38	7·09	72	9·76	130	13·12	300	19·92	540	26·73
5	2·57	39	7·18	73	9·83	135	13·37	305	20·08	550	26·97
6	2·81	40	7·27	74	9·89	140	13·62	310	20·24	560	27·22
7	3·04	41	7·36	75	9·96	145	13·85	315	20·40	570	27·46
8	3·25	42	7·45	76	10·03	150	14·08	320	20·57	580	27·70
9	3·45	43	7·54	77	10·09	155	14·32	325	20·73	590	27·94
10	3·63	44	7·63	78	10·16	160	14·55	330	20·88	600	28·17
11	3·81	45	7·71	79	10·22	165	14·77	335	21·04	610	28·41
12	3·99	46	7·80	80	10·28	170	14·99	340	21·20	620	28·64
13	4·15	47	7·88	81	10·35	175	15·21	345	21·35	630	28·87
14	4·31	48	7·97	82	10·41	180	15·43	350	21·51	640	29·10
15	4·46	49	8·05	83	10·48	185	15·64	355	21·67	650	29·32
16	4·60	50	8·13	84	10·54	190	15·85	360	21·82	660	29·55
17	4·75	51	8·21	85	10·60	195	16·06	365	21·97	670	29·77
18	4·88	52	8·30	86	10·66	200	16·26	370	22·12	680	29·99
19	5·02	53	8·37	87	10·73	205	16·46	375	22·27	690	30·21
20	5·15	54	8·45	88	10·79	210	16·66	380	22·42	700	30·43
21	5·27	55	8·53	89	10·85	215	16·86	385	22·56	710	30·64
22	5·40	56	8·61	90	10·91	220	17·05	390	22·71	720	30·86
23	5·52	57	8·68	91	10·97	225	17·25	395	22·86	730	31·07
24	5·64	58	8·76	92	11·03	230	17·44	400	23·00	740	31·28
25	5·75	59	8·83	93	11·09	235	17·63	410	23·29	750	31·49
26	5·87	60	8·91	94	11·15	240	17·81	420	23·57	760	31·70
27	5·98	61	8·98	95	11·21	245	18·00	430	23·85	770	31·91
28	6·09	62	9·06	96	11·27	250	18·18	440	24·12	780	32·12
29	6·20	63	9·13	97	11·33	255	18·36	450	24·39	790	32·32
30	6·30	64	9·20	98	11·39	260	18·54	460	24·66	800	32·53
31	6·41	65	9·27	99	11·44	265	18·72	470	24·93	850	33·52
32	6·51	66	9·34	100	11·50	270	18·89	480	25·19	900	34·50
33	6·61	67	9·41	105	11·79	275	19·07	490	25·45	950	35·45
34	6·71	68	9·48	110	12·07	280	19·24	500	25·71	1000	36·36

EXAMPLE.—When distant 20¾ miles, the top of a tower—200 feet high—will just be coming visible to an observer whose eye is elevated 15 feet above the water; thus, from the table

15 feet elevation, distance of horizon	4·46	naut. miles.
200 " " "	16·26	" "
	20·72	

This example may be put in another way.

The officer of the middle watch having, in the intervals of looking out ahead, kept his eye on a certain coast light on his quarter, notices that at last it is about to dip below the horizon, and wishing, like a sensible man, to verify his vessel's position, seeing that fog or thick weather may come on at any time, he carefully observes and marks down the bearing by standard

A hint.

2 X

compass. At the moment of disappearance he notes the time by wheelhouse clock and the patent log reading. He knows the height of his eye to be 15 feet, and the chart gives the height of the light at 200 feet; then by the Table the distance is found to be 20¾ miles.

The *corrected* bearing and above distance being laid off on the chart, of course fixes the vessel's position at the time recorded. When the officer of the watch, after being relieved, calls the captain at "eight bells," the latter is gratified to hear of the "fix," and being rendered easy in his mind, says "Thank you," requests to be called at daylight, and meanwhile turns over for another "caulk."

To check Light-ranges by the table is always advisable, as it not infrequently happens that books and charts give this item very incorrectly; and in any case it is manifest, from what has been said, that the range must depend upon the varying height of the observer's eye—whether he be on the lofty bridge of a large steamer, or on the main deck of a small vessel.

Elevation of Beacon lights calculated from High Water level

In the Admiralty Light List of the British Isles, the range is calculated for a height of eye of 15 feet, the elevation of the lights themselves being in all cases taken as *above High Water.* To remember this last point is of importance where the rise and fall of tide is considerable—as, for example, in the Bristol Channel, the Bay of Fundy, or the Gulf of St. Malo. With a tidal range of 30 feet, there would be a difference of six miles in the visibility of a light, according as it happened to be high or low water at the time of observation. Low Water gives the greatest range of visibility.

Necessity for checking Light Ranges by the Distance Table.

The range of the Cies Island light, on the coast of Spain, is, or used to be, given at 20 miles, but the writer often saw it at 33 miles. Reference to the table will shew that the latter is the distance at which, if it is a 1st order light, it ought to be visible to an observer elevated 25 feet, since its own height above the sea level is 604 feet. Now, there is a vast difference between 20 and 33 miles, and in many cases a departure, based upon such incorrect data, would lead to grief.

When looking out for a light at night, the fact is sometimes forgotten that from aloft the range of vision is much increased. By noting a star immediately over the light, a very correct bearing may be obtained from the Standard Compass before the light becomes visible to those on deck.

After all, even when every care has been taken, this mode of getting at the distance of lights by their presumed range is but guess-work. A great deal depends upon the clearness of the atmosphere, and more still upon the vagaries of refraction. For this latter it is impossible to make a correct allowance, and its effect is sometimes very startling.

Visibility of Lights unduly increased by Abnormal refraction.

At the commencement of the year 1881, the writer, then in command of the (s.s.) "*British Queen*" on her first voyage, was astonished, when making the American coast, to see—a full hour and a quarter before the proper time—a light, which, from its characteristics, could be no other than Cape May, unless, indeed, some alteration had been made of which he was not aware. As the vessel's position had been determined with great accuracy only a couple of hours previously, both by stellar observations and soundings, the unexpected appearance of this light was, for the moment, quite puzzling. When in doubt, the trump card to play in a case of this kind *is to stop*, which was done forthwith, and a careful bearing of the light taken by standard compass, the Deviation on the course *then steered* being well known from previous observations. Whilst busy getting a cast of the lead, the officer of the watch reported the sudden appearance of a fixed light on the starboard beam. Both lights shone with brilliancy. To get the correct bearing of this new light the horizontal angle between it and the first one was measured by sextant.

One bearing and a horizontal angle give a better "fix" than Cross Bearings.

This mode of doing it was rendered all the more necessary as the vessel's head had fallen off in the meanwhile to a point of the compass upon which the deviation was only imperfectly known.

The ship's place was first laid off by the course and distance made since the "fix" by stars, and the soundings on the chart were found to tally exactly with the cast just taken.

To make assurance doubly sure, the North * was next observed for latitude, which also agreed. There could, therefore, be but little doubt as to the vessel's true position. Assuming the lights to be those of Absecon and Cape May, their bearings, which crossed at a good angle (69°), were then laid down, and intersected most exactly at the position assigned to the ship, which, of course, was conclusive; so the engines were started ahead, and the course resumed. From this point to Cape May the distance was 35 miles, and to Absecon 29 miles.

The first-named light was 152 feet above the sea level, and should not have been seen further than 21 miles; whilst Absecon was 167 feet, and should not have been seen further than 22 miles. In 15 minutes, however, owing to some atmospheric change, the lights gradually lost brilliancy, and at last vanished altogether; and it was not until the vessel was some miles inside the *ordinary* range of Cape May light that it reappeared, although we were steadily approaching it all the time. In due course the Five-fathom Bank lightship was sighted and passed, and the position of our own vessel at time of stopping fully confirmed. The river was full of ice at the time, and this may have had something to do with it.

Some years previous to this occurrence, the writer saw the flash light on Sankaty Head at a distance of 38 miles, or 17 miles outside its usual range. In both these cases abnormal refraction had temporarily lifted the lights above the horizon, and made them visible at a point where, under ordinary conditions, such a thing would have been impossible. The reverse of this phenomenon occasionally happens.

This goes to shew that extraordinary departures from the general rule will sometimes occur, and points out the necessity for extreme caution; also the value of an *independent* check in cases where any error might lead into danger. There is no other profession whose members are obliged to be so constantly on the alert against accident brought about by freaks of nature, rendering unreliable the very materials they have to work with.

On first seeing a light, to know distance ship will pass from it.

If a vessel be provided with a good Azimuth Compass, the horizontal angle between the ship's course and a beacon light on its first appearance, can be used to determine the approximate distance at which the latter will be passed when abeam, provided always the same course be steered and *made good*. Having ascertained by the Range tables the distance of the light, open the Traverse tables at the given angle, and, with this distance in its own column, take out the corresponding amount in the departure column, which will be the passing distance required.

Suppose a vessel to be steering North by compass, and on the first appearance of a beacon light its bearing is taken as N. 16° E., and its range calculated at 20 miles. Open the Traverse tables at 16° and in the departure column will be found 5½ miles, opposite 20 in the distance column. But the navigator should not rest content with such an assurance, since tide or current, leeway or bad steering, might altogether falsify it.

Lord Kelvin's Azimuth Mirror.

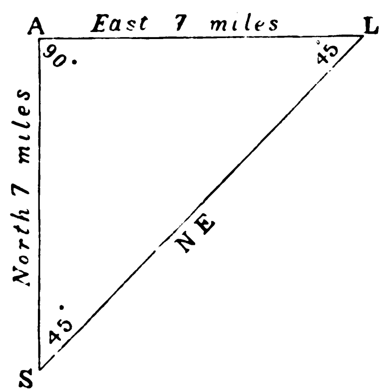
For an observation of the kind here referred to, the "Kelvin" Standard Compass is invaluable, as it is provided with what is in all respects a most perfect little instrument for taking *accurate* bearings by night or day. Friend's Pelorus is also good, and has the advantage of being portable, so that if the object of which the bearing is sought should be concealed in one position, the Pelorus can readily be moved to another. It has already been said that there should be a proper stand for the Pelorus on *each* side of the bridge. To use it for this purpose, clamp the lubber line to the course steered, and at the instant that an assistant intimates that the vessel is exactly on her course, take your bearing by the sight-vanes.

As the light is approached, a more accurate method of getting its distance when abeam becomes available.

Distance by Four-point bearing.

It is known as "Distance by Four-point Bearing." This method recommends itself to favour from its extreme simplicity and comparative accuracy. It is as follows:—When the light or other fixed object bears by compass four points (45°) from the course, note the exact time by watch or clock, and again do so when it bears on the beam, or 90° from the course. The distance run by the ship in the interval is the distance of the object when abeam.

For example, let a ship be steering North by compass at a speed of 14 knots. At 9 A.M. a lighthouse is observed to bear N.E., and at 9.30 it bears East. In the interval of half-an-hour the ship ran 7 miles, which, accordingly, is her distance off the lighthouse when abeam.



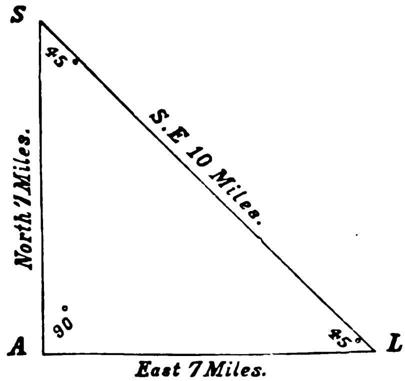
S is the position of the ship at 9 o'clock, when *L* bore N.E., or 4 points on the bow.

A is the position of the ship at 9·30, when *L* bore due East, or on the beam.

The line *SA* is the run in the interval, = 7 miles, and represents latitude. The line *AL* is the distance of the lighthouse when abeam, = 7 miles, and represents departure.

To prove this, open the Traverse Tables at the angle 45°, and the latitude and departure will be found equal to each other.

Should it be required to know the ship's distance from the lighthouse at the time of its bearing 4 points *abaft* the beam, recourse must be had to the Traverse Tables; and in the *distance* column, under the angle of 45° will be found the required information.

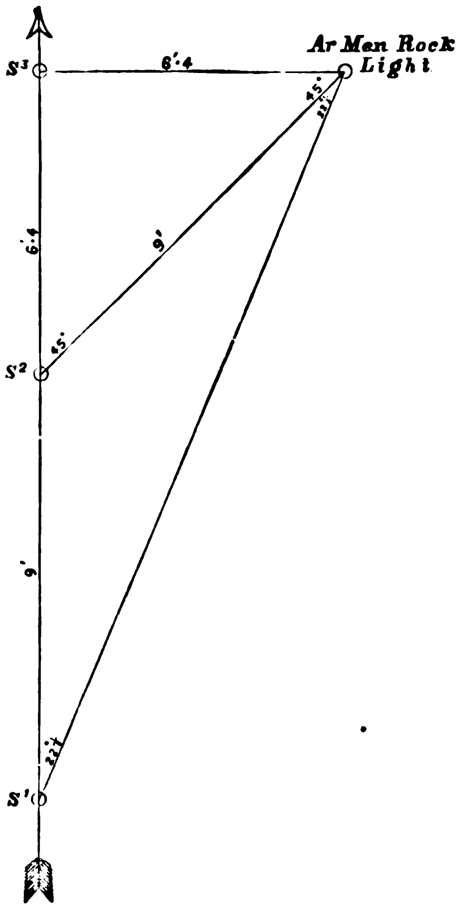


Thus, the ship having sailed on for another half-hour, = 7 miles, at which time *L* bore S.E., or 4 points *abaft* the beam, her distance from it would be 10 miles, and would serve as a departure.

This 4-point method of ascertaining distance is most convenient in practice, as the very trifling calculation required can be performed mentally without leaving the deck, and needs no reference to the chart. In this lies its great charm. It is manifest, however, that it cannot be considered *rigorously* exact, since either the speed or the course (upon both of which it depends) may have been influenced by tide or current. Still the method is a good one, *and the practice of it on all occasions should be a standing rule.* Indeed, it often happens—at night especially—that no other method is available which does not depend upon the same principle.

The 4-point bearing is the simplest exemplification of the rule that *whenever the angle between the course and the object is doubled, the distance run in the interval is the distance off at second bearing.* For example,—1st bearing 30° on the bow; 2nd bearing 60° on the bow; distance run between bearings equal to distance off at 2nd bearing.

Critics say truly that this method is defective in one respect, namely, that the Navigator sometimes requires to know the distance he is going to pass off the object *before* it comes abeam. For example, a certain cape might have an outlying sunken reef at a distance of some miles, and the distance by 4-point bearing might come too late to avert danger. "The Saints," on the N.W. coast of France, may be cited as a place where this could well happen. However, there is a way out of the difficulty without deserting our old friend the 4-point bearing.



Let a ship be steering north at a speed of 12 knots over the ground. Her intention is to pass a few miles westward of "The Saints." In due time the light on the Ar Men Rock is sighted a little on the starboard bow. At 8 P.M., when bearing exactly N.N.E. (2 points) the patent log is noted. After a run of 9 miles the light bore N.E. (4 points), and the time was recorded as 8.45 P.M.

As the first bearing has been doubled, the distance run in the interval is the distance off at second bearing, namely, 9 miles.

What ought to be a favourite method.

This distance multiplied by ·71 gives the distance the Ar Men Rock light *will be off when abeam.* Naturally, you will not omit to verify this by the 4-point method, of which, when at S^3, you have already taken the first half.

Here are the figures, ·71 × 9 = 6·39 miles, which will be the approximate passing distance.

At 9.17 P.M. the light was abeam, and, as the distance run between S^2 and S^3 was just 6·4 miles, the verification is satisfactory. The ship, therefore, passed 3¼ miles outside the western rock of "The Saints."

In practice it is more in keeping with the character of the problem to reject the second decimal and multiply merely by ·7. If you want to know why this factor is used, open the Traverse tables at 45°, and against 1 in the distance column you will find it. It is merely a question of the proportion of the sides of the triangle. By taking 10 as distance and shifting the decimal, the factor becomes ·71; and by taking 100 in the distance column and shifting the decimal it becomes ·707. But, as already stated, the nature of the problem does not admit of such refinements.

This is probably the best of the *bearing* methods: not its least recommendation is that it can be solved mentally. The weak spot in doubling a 2-point bearing is the acuteness of the angle. This is evident in the diagram, so do not expect more than approximate results.

When light is only seen when nearly abeam.

It often happens, also, that a light or other fixed object is not visible till nearly abeam. In such cases the 4-point method is not available, but the distance of the object can be found as follows:—

Note the time carefully when it bears exactly 26½° before the beam, and again when it has the same bearing abaft the beam. The distance run in the interval is the distance of the object *when it was abeam.*

These bearings, forming close upon an equilateral triangle *give a specially favourable result.*

EXAMPLE.

At 9 o'clock a light bore 26½° before the beam; at 9·15 it was abeam, and at 9·30 it bore 26½° abaft the beam. Ship steaming 12 knots against a 2-knot tide or current. Required the distance from the light at 9.15, when it was abeam.

Answer.—5 miles, which is the distance the ship made *over the ground* in the interval between first and last bearing.

It is not so long ago—indeed not further back than the 'seventies'—that off-shore distance methods were hardly known. Prior to that time, *cross-bearings* were the staple commodity. Failing these, there was the Ark-adian plan of observing two bearings of an object, regardless of any particular angle, and by calling into action the parallel ruler and dividers, and wrestling with a refractory chart that had been rolled up for nigh upon a twelvemonth, the position was finally determined *after a fashion.* But in those days ships did not steam at the rate of 25 miles an hour.

Antediluvian methods.

Now, it is the other way about, and the Navigator is deluged with any number of gimcrack methods, tables, diagrams and brazen instruments. Some of these latter are wonderful. At a cost of £10, more or less, and after a few weeks of study, they can be made to do what a simple-minded person (not an inventor) would perhaps be stupid enough to think could be done equally well with the ordinary tools of the trade, and a few pencil figures on the helmet of the binnacle. In fact, a New Era has dawned upon Navigators in the matter of Position-Finding, and henceforth no inconsiderable part of their time in port will be spent in resisting the invasions of inventors. There *may* be people who consider a 50-ton steam hammer the best thing with which to crack nuts, but the writer is not one of them.

It is not proposed in these pages to bewilder with cartloads of methods having no special recommendation; and, keeping in view that the great point to be achieved now-a-days is to be able to get the required distances accurately, quickly, and without leaving the deck, we will restrict ourselves to an exposition of the only two other *bearing* methods likely to be of service.

Should a bearing before or abaft the beam be observed at *any* angle on the bow or quarter, the distance when abeam can readily be obtained by multiplying the distance run in the interval by a factor taken from the subjoined Table. The limits given are sufficient for practical purposes:—

Handy Factors

°		°		°		°		°		°	
39	·81	45	1·00	51	1·23	57	1·54	63	1·96	69	2·61
40	·84	46	1·04	52	1·28	58	1·60	64	2·05	70	2·75
41	·87	47	1·07	53	1·33	59	1·66	65	2·14	71	2·90
42	·90	48	1·11	54	1·38	60	1·73	66	2·25	72	3·08
43	·93	49	1·15	55	1·43	61	1·80	67	2·36	73	3·27
44	·97	50	1·19	56	1·48	62	1·88	68	2·48	74	3·49

EXAMPLE.

The time when a light bears 60° on the bow is noted, and also, of course, when it is abeam. The run in the interval is 10 miles. Required distance from light when abeam.

$$60° = 1{\cdot}73$$
$$\times\ 10$$
$$\overline{17{\cdot}30 \text{ miles.}}$$

Or, enter Traverse Table at 60°, and against 10 in Latitude column will be found 17·3 in Departure column. Also, in the Distance column will be found 20, the distance of light at first bearing. It is handy to have a small "black board" and piece of chalk, on the bridge, to figure out these things. On the darkest night the chalk marks can be seen by a keen-eyed officer. The board should be a fixture.

Good method for regular Liners.

The next method demands a little more preparation, but this can be done at leisure. Many vessels are continuously employed in one trade, and consequently frequent certain coasts. Once more it is repeated that such vessels, more particularly, should be furnished with the best and largest scale coast sheets procurable.

On these, connect by a *red* line the various lighthouses, points, or other conspicuous marks which exist within sight of each other, say at distances not exceeding 10 or 12 miles. Measure these distances *very carefully*; also the mag. bearing from one to the other, and write them down on their respective connecting lines.

Exactly at right angles to these bearings draw red lines seaward of an indefinite length. They should exceed by a few miles the distance at which you are in the habit of passing the points in question. Then you are ready for action.

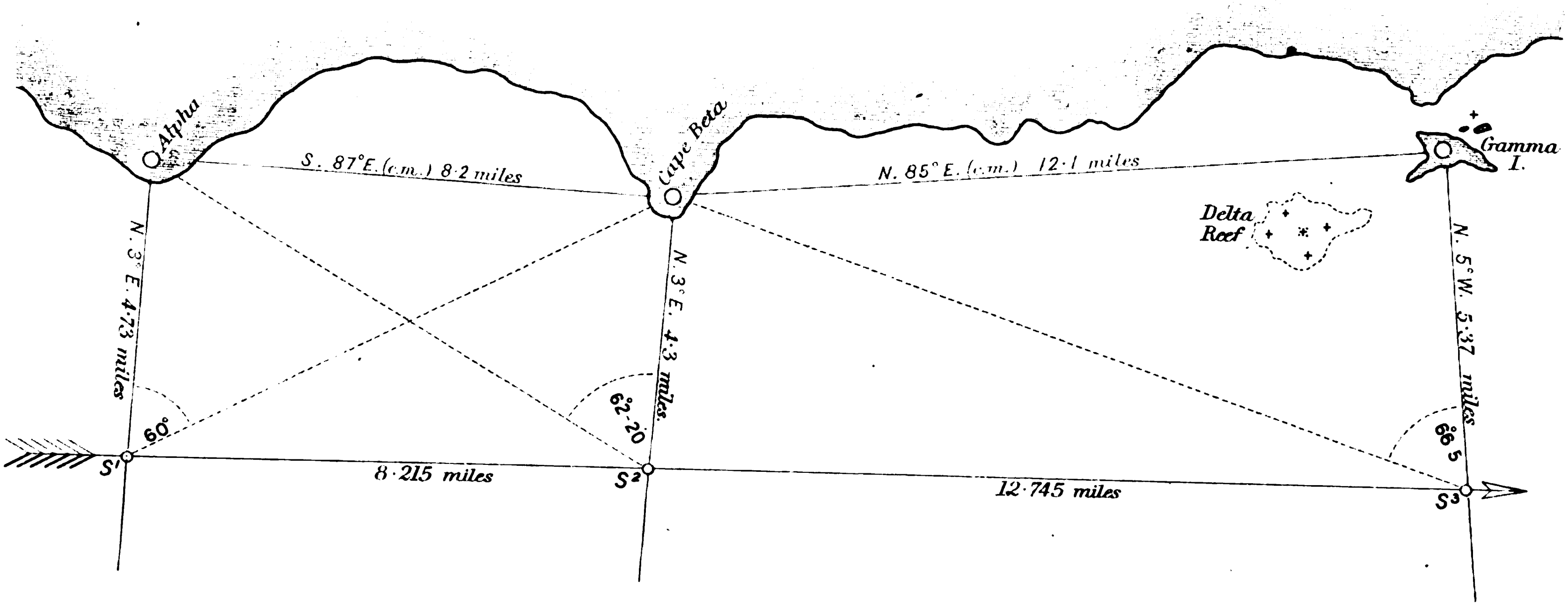
Of course, it is not intended that the charts should be plastered all over with these lines. The Navigator will know by experience where he wants them, and will act accordingly.

By way of illustration, take the cut facing this page. The ship is steering East (M.), and passing in turn the lighthouses *Alpha*, *Beta*, and *Gamma* (evidently it must be the coast of Greece). It is required to know her distance off on the bearings given. Let the ship be approaching the position marked S^1. The Navigator notices that the red bearing line of *Alpha* is N. 3° E. (M.), and having, say, 5° of westerly deviation on the course he is steering, the *compass* bearing of *Alpha* becomes

Scale 1 inch = 3 miles.

SHIP'S COURSE, EAST (m.)

S^1 to S^3 = 21 MILES.



TO FACE PAGE 688

N. 8° E. Sextant in hand, he stands at the compass, and at the moment when the bearing comes on, he snaps the horizontal angle between *Alpha* and *Beta*, say 60°. At the same moment the officer of the watch records the time and patent log reading. **A bridge method.**

Now the Rule is,—multiply (on your cuff if you like) the Natural cotangent of observed angle by the shore base, and you get your distance from the *nearer* object.

On page 725 Raper gives a Table of Natural sines, tangents, &c., but only to degrees, and this is hardly good enough. Chamber's Mathematical Tables (No. 5, extra, of Nautical Library) gives them *in extenso*, which perhaps is a little *too* good for this particular purpose, so to meet the want the Author has inserted Nat. cotangents, cosecants, &c., in his *Danger Angle and Off-shore Distance Tables*, referred to further on. Now for the distance from *Alpha*.

Nat. cotang. 60°	·577	using only 3 decimals.
Shore base	× 8·2	miles.
	1154	
	4616	
Distance	4·7314 = 4¾ miles.	

But two decimals in the Nat. cotang. would be ample; thus,—

·58
× 8·2
116
464
Distance 4·756 = 4¾ miles as before.

This distance is pricked off on the fixed red line, and the position is determined as being at S^1.

The vessel continues on her course, and as S^2 is approached the same process is repeated. The *compass* bearing of *Beta* is also taken as N. 8° E., but the observed angle this time is 62° 20′ nearly; therefore

Nat. cotang. 62° 20′	·524
Shore base	× 8·2
	1048
	4192
Distance of *Beta*	4·2968 = 4¼ miles.

Here again two places of decimals would suffice.

This distance is pricked off, and the position is determined at S^2. The course is continued, and the Navigator, allowing the 5° westerly deviation, arranges to measure the angle between *Beta* and *Gamma* when the latter bears North *by compass*. This he does, and gets the angle 66° 5′; therefore

Nat. cotang. 66° 5′	·443
Shore base .... ×	12·1
	443
	886
	443
Distance of *Gamma*	5·3603 = 5⅓ miles.

Two decimals would give 5·424.

Current, or Log error.

On pricking this off, the position is determined at S^3. The actual distance from S^1 to S^3 is nearly 21 miles, but the patent log shewed 23. Therefore there was either a current against the ship or the patent log had an error of 8¾ *per cent.* The course was made good exactly.

Anyone who follows out the foregoing will see that in each case the position is *accurately* fixed in less than a couple of minutes after taking the angle, and can be entered in the rough log at once without leaving the deck. The officer of the watch should be required to do a simple thing like this as a matter of *regular routine.* By this means the ship will be navigated on business principles, instead of trusting to luck: there will be no "guessing" or "estimating" the off-shore distances: they will be exact; and all with next to no trouble. Should it be required by the Master to mark the position on the chart, he has merely to take the distance from the log-book and prick it off on a line *already existing.* Parallel rulers are not even required; nothing but dividers. What *can* be simpler or easier? If the distance of the *further* object be desired, it is only necessary to multiply the shore base by the Natural *cosecant* of the observed angle instead of by the Natural cotangent. The student will perceive that all these cases can be solved, if desired, by the Traverse Tables, since the triangles are right-angled.

"Rake of the eye."

Pilots, in the absence of definite leading marks, are in the habit of judging their position by what they term "the rake of the eye"—a loose plan, which, to say the least of it, is unsatisfactory, since no three individuals on board ship will agree in their *estimate* of distance or of height, and, at times, appearances deceive even the most experienced; so that, under certain conditions of coasting, *exact* methods become a necessity. Fortunately, as already shewn, there are such methods; and the opportunity for employing them is both greater and less troublesome than is generally supposed. We will now introduce some more of a rather different type.

Comparatively few men are aware what a powerful ally they possess in the Sextant for the determination of distance, and to enable them to fix a ship's position with all needful precision when in sight of land. Judgment may be at fault—for man is not infallible; but angular measurements are reliable matters of fact.

In the chapter on the Station Pointer, it was shewn how two simultaneous horizontal angles, subtended by three well defined objects, gave an exact "fix;" also, how an angle between two objects in transit and a third, was equally good, if not better. In these cases the angles measured are *horizontal* ones; but it is now proposed to shew that *vertical* angles, combined with a compass bearing or not, as the case may be, will fulfil the same purpose, and sometimes be available when the others are not.

"Fix" by *vertical* angle and Compass bearing.

On the Admiralty charts, the heights of all beacon lights are given, as well as those of most of the islets, rocks, hills, cliffs, and mountains along a line of coast. Each of these, then, are available as bases in a right-angled triangle, by which to determine their distance; but when the vertical angle is small, *and the distance considerable,* the angle must be measured with all possible accuracy. To do so, the sextant telescope should be employed, and the angle observed both "on and off" the arc. The mean of the two readings will then be free from index error. But if the object be near,—say a lighthouse on the edge of a cliff, about a mile or so away,—it will be sufficient to measure its altitude in the usual manner, and apply the index error previously determined.

Arc of excess

The divisions of the limb of every sextant are continued for a few degrees to the right of zero, and this is known as the "Arc of excess." For example, suppose it were required to measure the vertical angle between the summit of a *distant* mountain and the sea horizon underneath it. This is a case in which, unless the ship were steering directly towards or from the mountain, the angle would alter very slowly, and is one where the "on and off" reading should be employed. By moving the index bar of the sextant *forward* from zero, the reflected image of the *summit* would be brought *down* to the actual horizon, as seen

"On and off" measurement.

directly through the horizon glass, and the reading would be made in the ordinary way. Starting again from zero, and moving the index *backwards*, the reflected image of the *horizon* will be brought *up* to the actual summit of the mountain, as seen by direct vision through the horizon glass.

To get the value of the angle in this last case, both the limb and the vernier must be read *from left to right*. Suppose the sextant limb to be divided to 10′, then 10′ of the vernier would have to be considered 0′ or zero, the 9′ taken as 1′, the 8′ as 2′, the 7′ as 3′, and so on. A little practice will soon overcome any difficulty which may at first be experienced in doing this. To utilise quickly the vertical angle, and to render the method complete, a set of tables is necessary, so that the required distance may be taken out *by inspection.*

There is a handy little book by the late Captain Becher, R.N. (published by Potter, 145, Minories, London), in which the angles are calculated for heights from 30 to 280 feet, and distances varying from a cable's length to four miles. The small scope of this book, however, only fits it for use where the object of which the angle is measured lies at a less distance than the visible horizon. The author's intention was that it should be employed more particularly in experimental squadrons, for finding the distance of one ship from another by her masthead angle.

Lecky's Off-shore Distance Tables.

To give a wider scope to this vertical method, the writer has published an extended set of somewhat similar Distance Tables, in which angles are given for heights from 50 to 18,000 feet, and distances from a tenth of a mile up to 100 miles. Part I. of the Tables is intended to be used with objects not exceeding 1,000 feet in height, which lie *on* or *within* the radius of the observer's horizon; and Part II., where curvature has to be taken into consideration, is for more elevated objects lying *beyond* the observer's horizon.* The book is pocket size.

By these Tables (Part I.) the distance from an object can be taken out absolutely *at sight*, without the necessity for any figuring whatsoever. It may now and again happen, however, that the height of the object exceeds 1000 feet, the limit of Part I., in which case use the following rule.†

Multiply the height in feet by ·565, and divide by the number of

* The Danger Angle, and Off-shore Distance Tables. Price 4s. 6d. Philip, Son and Nephew.

† In the 4th Edition, Part I. has been extended to 1100 feet.

minutes in the angle between the summit and the water-line: the quotient will be the distance in nautical miles and decimals of a mile.

Thus, in passing Ailsa Craig (Firth of Clyde) it subtended an angle of 1° 57′ when abeam, the observer being elevated 26 feet. The given height of the Craig is 1097 feet, but for sake of round numbers call it 1100 feet. Required the distance to a point vertically under the summit.

```
                      1100 feet.
                      ·565 constant factor.
                      ----
                      5500
                     6600
                    5500
                   -----------m.
Sextant angle 117′) 621·500 ( 5·312 distance.
                    585
                    ---
                     365
                     351
                     ---
                      140
                      117
                      ---
                       230
                       234
                       ---
```

Tables of Logs. are not required

This rule is quite independent of Tables of any kind; as you have merely to remember the constant ·565.

The same result may be achieved by yet another plan, though not nearly such a convenient one.

Rule.

Divide the Natural Cotangent of the angle of elevation by 6080, *and multiply the quotient by the height in feet of the object.* This will give the distance in nautical miles.

Tables are required.

Example.

Passing a small island, a peak of which is marked on the chart as 700 feet high, the observed vertical angle of same was 1° 53′. Required the distance of the ship from the part of the island referred to.

```
              Nat. Cotang.
6080 ) 30·411580 ( ·005002 nearly.
       30·400          × 700
       ------      -------------
        11580      3·501400 miles.
        12160
        -----
```

For verification see page 33 of the author's Tables.

These methods require pencil and paper, and involve delay; whilst, therefore, they are not so handy as the Tables, they serve well on a pinch, and are perfectly accurate. They are restricted to objects *on* or *within* the observer's horizon.

An American novelty.

In July, 1882, Commodore J. G. Walker, Chief of Bureau of Navigation, United States Navy, courteously sent the author a "Diagram for finding Distances and Heights." On comparing the results obtained by this ingenious contrivance with those taken out of Part II. of the Tables, they proved in every case identical. This correspondence between calculation and construction served of course as a voucher for the accuracy of each. The diagram, however, is not so handy for reference as the Distance Tables—especially on deck, where its size (24″ × 19″) would render it liable to be taken charge of by every puff of wind, as well as injured by rain or spray. The diagram also lacks the advantages to be derived from Part I. of the Distance Tables. The inventor is H. Von Bayer, C.E., and the price one dollar.

Vertical Danger Angle.

To shew the practical utility of this vertical angle method, let us suppose that the navigator, for some important reason, such as meeting a crowd of vessels, is forced to round more closely than he otherwise would, the Skerries lighthouse on the coast of Anglesea. He knows, however, that at 3 cables from it there is the hidden African rock, which he had better pass at least two cables outside of to ensure safety; this makes in all 5 cables from the lighthouse. His chart gives the height *of the light* as 117 feet above the level of high water. Opening the Distance Tables, therefore, at 120 feet (since it is scarcely likely to be high water at that precise moment) he finds opposite 5 cables the angle 2° 15′ 38″. This, when corrected for index error, is placed upon the sextant, and so long as the angle subtended between *the centre of the lantern* and the water-line beneath it does not exceed this amount, he knows he is at, or outside, the prescribed distance.

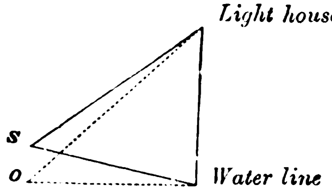
Points of measurement.

Attention is here called to the fact that the angle is measured *not* to the cowl or top of the lighthouse, but to *the centre of the glass lantern*, or, in other words, to a point representing the height of the focal plane of the light above the level of the sea. If it be desired to measure from the extreme top of the lighthouse to its water-line, the following is the approximate number of feet to be added to the given height of the light:—

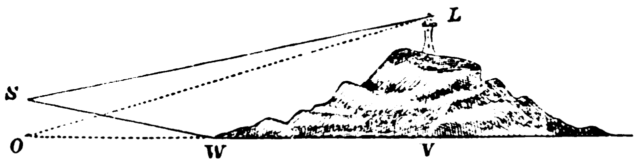
1st	Ord. light, from centre of the light to the vane is *about*						17 ft.	9 in.
2nd	„	-	-	-	„	-	„	14 „	6 „
3rd	„	-	-	-	„	-	„	12 „	6 „
4th	„	-	-	-	„	-	„	8 „	6 „
5th	„	-	-	-	„	-	„	7 „	6 „
6th	„		-	-	„	-	„	7 „	6 „

In connection with this matter of taking vertical angles, one point deserves notice. When the object is near, the observer should get as low down as possible, to lessen the error which would arise from his eye not being on the level of the water-line, to which the angle is measured.

Precautions to be observed in measuring Vertical Angles.



S represents the angle as measured from the bridge, and *O* what it would be if measured from the sea level. Except, however, in exaggerated cases, the difference is not large; and as the angle at *S* is greater than the angle at *O*, the error lies on the safe side, if the injunction to descend is disregarded, so long as there exists no danger *outside* of the ship.



A palpably bad case.

This second case is one to be guarded against, as the error involved is considerable. It represents a ship passing a lighthouse, standing on a hill, say some two miles inland; whilst in the foreground, at *W*, is a low rocky point. The angle *S*, subtended by *L* and *W*, is clearly too great; it ought to be measured between *L* and *V;* but as this is impossible from there being no way of ascertaining the whereabouts of the imaginary point *V*, the difficulty is practically got over by descending to as near the point *O* as you can get.

On the other hand, when measuring the vertical angle of objects *beyond the horizon*, it is desirable that the observer should be as high as he can conveniently get. The words water-line and horizon must not be understood to mean the same thing.

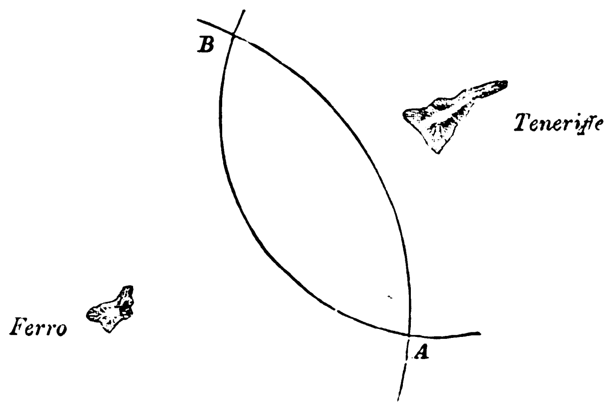
Distinction between *Water-line* and *Horizon*

The horizon is the natural boundary line where the sea and heavens apparently meet each other, and its distance—a direct consequence of the earth's curvature—depends upon the elevation of the observer. The distance of an object's water-line, on the contrary, has nothing to do with the elevation of the observer. Attention to these and other delicate points constitutes the *expert* navigator.

When a distant mountain peak is visible above the sea horizon, a ship's position may be fixed, with a near approach to accuracy, by measuring its "on and off" altitude, and laying off on the observed line of bearing the corresponding distance taken out from the tables by inspection. Or the Compass may be dispensed with altogether if the Astronomical bearing be found by a second observer in the manner indicated on page 617.

"Fix" by two vertical angles without bearing.

Should *two* summits be observed simultaneously, or nearly so, which are separated by a considerable horizontal angle—the nearer to 90° the better—the ship's place will be found by simply sweeping the distance from each with the dividers. It is true the circles will intersect at *two* points, but the eye alone, or a rough bearing, will easily determine which is the ship's position.



Let the diagram be supposed to represent any two neighbouring islands—say Ferro and Teneriffe, both of which are lofty—and let the arcs of circles represent their respective distances from the ship. Then the latter must either be at A or at B; and it is almost needless to say there can be no difficulty in deciding which. In all these cases where vertical angles are measured, the greater the height of the object, and less acute the observed angle, the more reliable will be the result.

When well out in the offing, known mountain peaks are frequently visible, and form salient features, when the coast-line—indistinct through distance or haze—offers no points by which to get a "fix." This is very much the case on the coasts of Chile and Peru. Moreover, should a vessel be standing in from seaward to make her port, what a source of satisfaction it is to be able to define her *precise* position, and shape a correct course for it before the coast-line is even visible, and this with scarcely any trouble.

The Sextant has a vast superiority over the Compass in a number of cases. This is particularly well shewn in the problem known as the "Danger Angle," where the compass is scarcely of any service whatever. It is no disparagement, however, to the compass to say that it cannot do *everything*, or that there are other instruments which, in particular cases, should supersede it.

The Danger Angle.

The "Danger Angle" may be measured either vertically or horizontally, according to the features of the coast. Let us take a vertical one first—of which a good example has already been given in the case of the Skerries Lighthouse and African Rock. It was there shewn that so long as the angle did not exceed 2° 17′ 26″, the vessel would pass two cables' length outside the danger. Similarly with the South Rock off Tuskar. This can be rounded in safety if the angle between the water-line and the top of the lighthouse is not allowed to exceed 1°; but in such a situation, where the tide runs strongly, the angle would require to be narrowly watched; and, unless pressed in by having to port for another vessel at the critical moment, there is no object in making such very close shaves with plenty of sea room on one side—although at the same time, be it said, ordinary skill and care should obviate the necessity for throwing distance away as if it cost nothing. Moreover, there are thousands and thousands of spots where dangerous shoals *have* to be threaded without the aid of a pilot, and then this sort of knowledge is worth a Jew's eye.

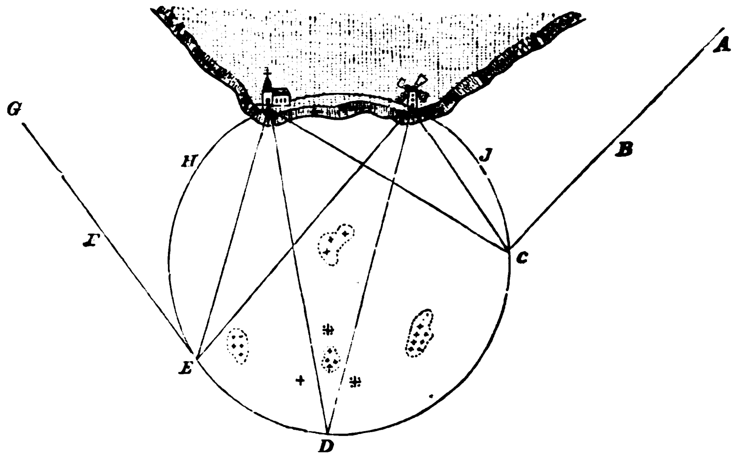
Vertical Danger Angle

The peculiar and very convenient property of the circle, namely, the equality of angles in the same segment, permits of the second or horizontal application of the "Danger angle."

Horizontal Danger Angle.

In the diagram the line *ABCDEFG* represents the course of a ship as she rounds a promontory, off which lie several dangerous rocky shoals. Having decided to give the reefs a berth of half a mile or so, a circle is drawn passing that distance outside of them, and through the church and windmill on the cliff. Then measure with a protractor the angle at *D*, subtended by the aforesaid church and windmill, which of course, in an accurate survey, will be laid down in their proper places on the chart. The angle in the present instance is 25°, and may be termed

The Danger Angle—horizontal



the "Danger angle." It will be found to be the same for *all* parts of the circumference of the circle seaward of the two marks, no matter whether measured at *J*, *C*, *D*, *E*, or *H*. Therefore, so long as the observed angle is *less* than 25°, the vessel must be outside of the circle, and *in safety*; but if the angle be *greater* than 25°, she is evidently *inside* the circle, and *in danger*.

As depicted above, the vessel is standing alongshore on the line *ABC*, but as she approaches the pitch of the cape her commander, who is on the alert with his sextant, gets the "Danger angle" at the point *C*. Thus warned of his being too close in, he at once starboards and hauls off, steering so as to avoid increasing or unnecessarily diminishing the angle until the point *E* is gained, when the course *EFG*, along the coast, causes the angle rapidly to decrease, and tells the danger is passed.

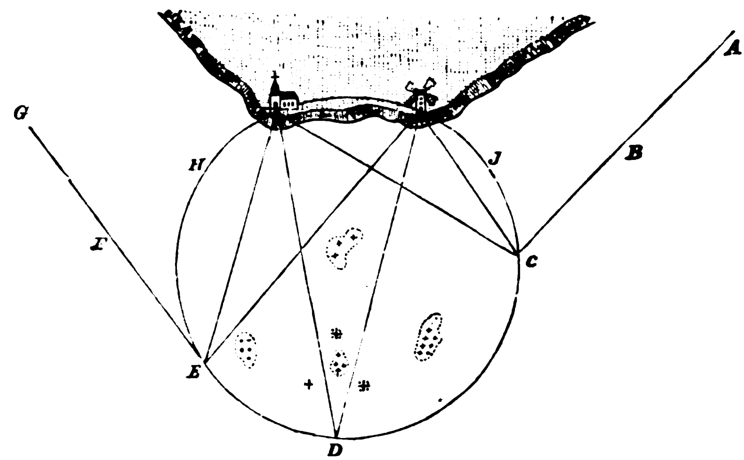
It is manifest that compass cross-bearings here would be of no use, since the cut made by a difference in the bearings of only 2¼ points is too acute to be in the least reliable.

Supposing the height to be known of the cliff or of the church, a second observer could independently verify the distance by the *vertical* "Danger angle," so that not only could the navigation be conducted with the utmost safety, but without losing ground.*

* As a rule it is safer to navigate in the vicinity of doubtful ground during roughish weather than during fine, since sunken rocks carrying only three or four fathoms over

measure with a protractor the angle at D, subtended by the aforesaid church and windmill, which of course, in an accurate survey, will be laid down in their proper places on the chart. The angle in the present instance is 25°, and may be termed

The Danger Angle—horizontal



the "Danger angle." It will be found to be the same for *all* parts of the circumference of the circle seaward of the two marks, no matter whether measured at J, C, D, E, or H. Therefore, so long as the observed angle is *less* than 25°, the vessel must be outside of the circle, and *in safety*; but if the angle be *greater* than 25°, she is evidently *inside* the circle, and *in danger*.

As depicted above, the vessel is standing alongshore on the line ABC, but as she approaches the pitch of the cape her commander, who is on the alert with his sextant, gets the "Danger angle" at the point C. Thus warned of his being too close in, he at once starboards and hauls off, steering so as to avoid increasing or unnecessarily diminishing the angle until the point E is gained, when the course EFG, along the coast, causes the angle rapidly to decrease, and tells the danger is passed.

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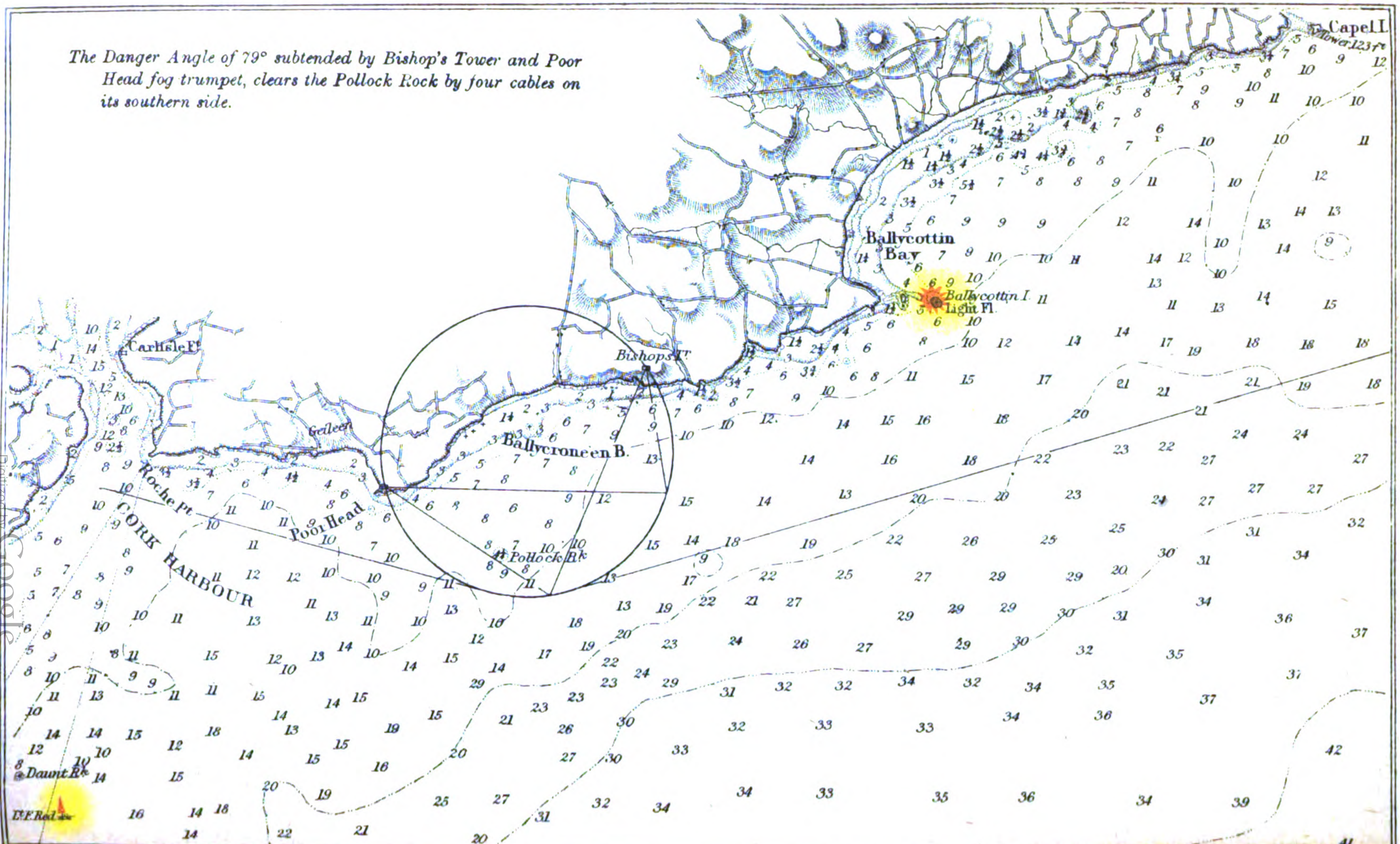


The Danger Angle of 79° subtended by Bishop's Tower and Poor Head fog trumpet, clears the Pollock Rock by four cables on its southern side.
Capel I.
Tower 123 ft
Ballycottin Bay
Ballycottin I.
Light Fl.
Bishops Tr.
Ballycroneen B.
Pollock Rk.
Poor Head
Roche Pt.
Carlisle Ft.
Gealeen
CORK HARBOUR
Daunt Rk.

This horizontal method may be employed in a great variety of ways, and has the special advantage that the man in charge of the navigation, after having once drawn his circle and measured the danger angle, has no need to leave the deck and attempt hurriedly to lay off unsatisfactory bearings on a chart. He has a hard and fast angle, and so long as he does not *increase* it, he knows without any other guide that his ship is safe. For those running steadily in certain trades, it is advisable to have the "Danger angles" tabulated for the various parts of their route requiring them. Less would then be heard of losses through "errors in judgment."

For example: off the coast of Brazil, the Abrolhos* lighthouse stands on one of a small group of islets out of sight of land, which islets are surrounded by sunken coral reefs extending seaward several miles. This group of islets is circular in shape; and so long as they subtend a horizontal angle not greater than 7° 20′, it is impossible to touch the reefs on the eastern side. **Abrolhos reefs**

Liverpool navigators, running in the North Atlantic steam trade, are all familiar with an awkwardly situated danger on the south coast of Ireland known as the Pollock Rock. The Admiralty surveyors found on it not less than 4¼ fathoms, but the local fishermen say that it has a spot with only 3 fathoms. Every one experienced in such work knows how extremely difficult it is to find the shoalest points of a reef, principally on account of the lead slipping off when the rocks are cone-shaped, and as this ridge is some 400 feet in extent, it is quite likely the fishermen may be right. **Pollock Rock.**

Lying, as it does, slap in the eastern fairway to and from Queenstown, it is a regular *Bête noir*, and from the absence of good clearing marks, in hazy weather or at night, requires a wide berth.

Here the "Danger angle" comes in as a perfect safeguard. So long as the horizontal angle between the fog-trumpet on Poor Head and Bishop's Tower, some 3½ miles to the eastward, does

them, will not break in smooth water, but will unmistakably do so when there is any sea.

Note.—*Have an intelligent quick-eyed officer at the masthead under such circumstances.*

In Magellan Straits and other parts of the world sunken dangers are buoyed, so to speak, by "Kelp," and this is almost an unfailing guide during daylight; but it should be known that where the currents are strong, "Kelp" is often run under. "Live Kelp"—which is the term given to the weed when rooted to the rock—is easily distinguished from loose or "dead Kelp:" the one is oily looking, combed out and streaky; the other drifts about in tangled masses. **"Live Kelp—a sign of danger**

* Abrolhos is compounded of two Portuguese words, signifying "Open your eyes."

not *exceed* 79°, you will—when at nearest approach—pass four cables outside the rock. To strike it the angle would require to be about 93°.

The fog-signal station on Poor Head, with its white boundary wall, is unmistakable, and the trumpet is quite conspicuous at the western end of the enclosure. Bishop's Tower is situated on high ground midway betwen Poor Head and Ballycottin lighthouse. With the binocular it is easily got hold of, and once recognised and impressed on the memory there is no after trouble in doing so.

Horizontal Danger Angle.

To ascertain the "danger angle" for any place possessing suitable marks is a simple matter:—choose two conspicuous objects which are laid down on the chart, and if possible let them lie about an equal distance on each side of the danger. Put a pencil dot on the chart at the distance you wish to pass from the danger, and then draw a circle through the two selected objects and the pencil dot. The centre of the circle may be found by trial or as described in foot-note.* Next connect the pencil dot with each of the marks by a fine straight line, and, with a protractor of any kind, measure the contained angle. This angle, as already stated, will be found to be the same at *any* point in the circumference of the circle.

Of course if it were desired to pass *inside* the Pollock Rock, another circle could be drawn to suit the new condition. In this case, to give the rock a berth of 4 cables on the inshore side, the "Danger angle" must not be *less* than 117°—an inconveniently large angle to measure with the sextant, but it might be possible to select more suitable objects. When taking the inside passage *beware of the "Hawk" and other sunken rocks off Poor Head.*

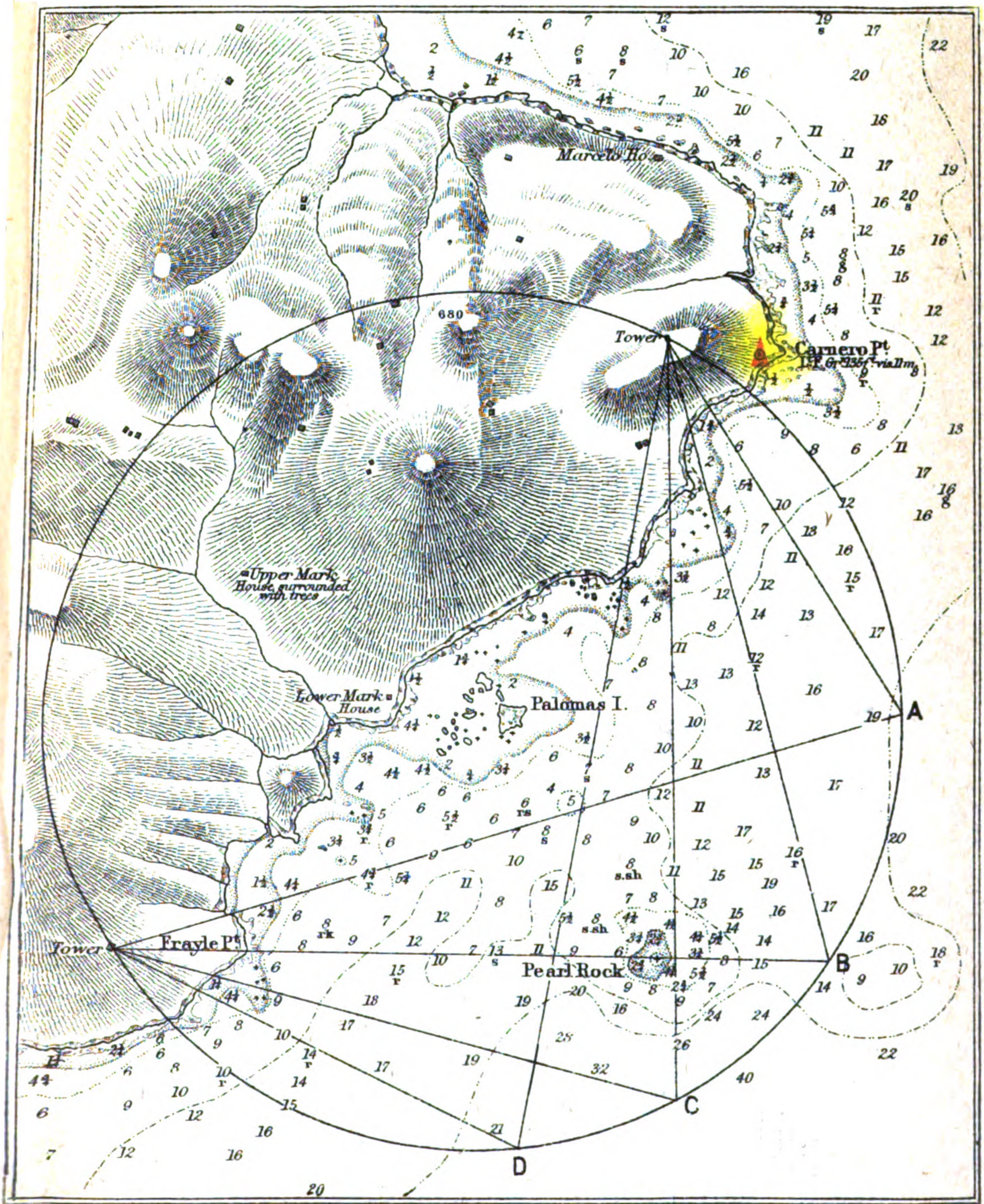
Pearl Rock.

Entering or leaving Gibraltar Bay on the west side, the Pearl Rock (on which H.M.S. *Agincourt* was nearly lost) has to be guarded against. The horizontal "danger angle" to pass 2½ cables (or a quarter of a mile) outside it, is 74°. This angle is to be measured between two very conspicuous square towers, the one situated on a hill overlooking the lighthouse on Carnero Point, and the other on the hill above Frayle Point.

Whether measured at the points in the diagram marked *A*, *B*,

* To find the "Danger angle" (horizontal), it is necessary to know that a circle can be drawn to pass through any three given points, no matter how situated, provided they do not lie in the same straight line. In the adjoining figures, a circle, whose centre is at *C*, is drawn through the given points *ABD*. The centre is found by the intersection of the dotted lines *FC* and *GC*. *Vide* Chapter XI., on *Station Pointer.*

PEARL ROCK "DANGER ANGLE." (74°)



TO FACE PAGE 700

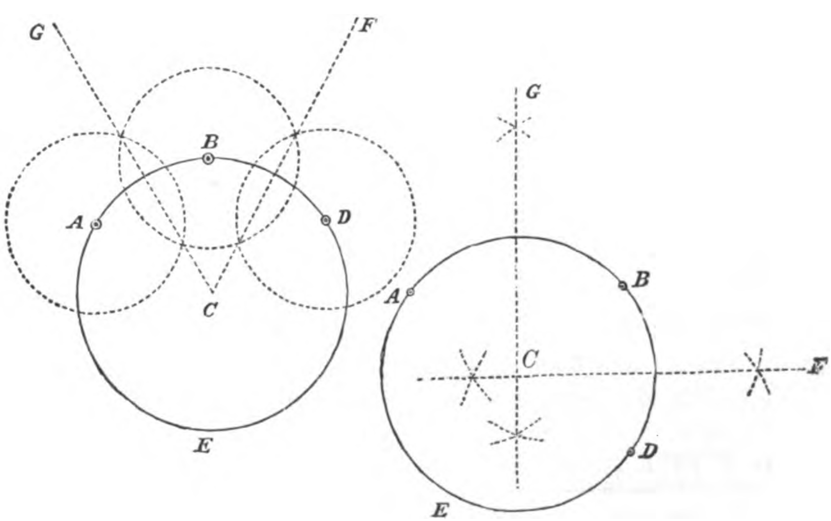
C, D, or any other part of the circle *seaward* of the towers, the angle is still 74°.

Entering River Tagus by Danger Angle.

Again, in going into the port of Lisbon after dark, before the present range lights were established, the only guides to avoid the North and South Cachopos were the Compass bearings of San Julian and Bugio lights; but it often happened in winter that there was a heavy run on the bar, which sent the compass-cards spinning, and so rendered them utterly useless at the time of all others when most wanted; besides, in any case it would have been impossible to leave the bridge to lay off bearings at such a critical time.

The writer, however, has entered with comparative ease on very stormy nights, when no pilot could be had, by steering so as to maintain the "Danger Angle" of 71° between Guia and San Julian lights, until those of Bugio and San Julian subtended nearly the same angle (68°), when the worst was passed, and it merely remained to con the vessel by eye mid-channel between the two last-mentioned lights.

If, by bad steering or otherwise, the "Danger angle" between the first pair of lights was allowed to be greater or less than 71° at the moment the "Danger angle" came on between San Julian and Bugio, it shewed the vessel was not in mid-channel. In the event of the angle being greater than 71°, she was on the North side of the fairway; and if less, it placed her on the South side.



For a solution of this and other equally interesting Problems in Practical Geometry, see *Raper*.

So long, however, as the "Danger Angle" between Guia and San Julian did not exceed 84°, or be less than 70°, there was not any cause for alarm.

By way of practice, these "Danger angles" might be laid off on Admiralty Plan No. 89, which gives the entrance of the River Tagus.

Sextant versus Compass.

It would hardly be wise, however, to make one's *first* experiment with the "Danger angle" under critical conditions such as those just described, nor would it be fair play to the method. Better, by far, to practise where no risk is incurred, until a perfect mastery of the principles gives confidence in their power. The foregoing examples afford conclusive proof that the Sextant is often of greater use in pilot waters than the Compass—not that the latter, after centuries of good service, is to be despised and forsaken; that time has not yet come. Each of the two instruments is good in its place; and it is the object of these pages to point out more particularly those cases where, with advantage, one may be employed in preference to the other.

Best way to take *accurate* Cross-bearings

To conclude this subject, it should always be borne in mind that, in taking cross-bearings, the better plan is to observe but *one* compass bearing—whichever is most conveniently situated for the purpose—and then, with the sextant, take the horizontal angle between the two selected objects. The second bearing is, of course, got by applying the sextant angle to the right or left of the first one, as the case may require.

Get into a habit, and make your officers do the same, of noting and marking down *there and then* the exact time of all such observations. This is becoming more and more important as the speed of steamers increases. Twenty miles an hour is not now uncommon, and it means *a mile in only 3 minutes*—indeed, with a strong favouring tide—in less than 3 minutes.*

EXAMPLE.—Being off Holyhead, observed the Skerries lighthouse to bear S. 84° E. by compass at 10.7 A.M. by watch, the sextant angle between it and the South Stack lighthouse being 80° at the same moment. The latter, therefore, bore S. 4° E. by same compass; and the cut, being nearly a right angle, gives a good "fix." Patent log shewed 23¼ miles. (Apply deviation.)

Set and rate of tide.

Exactly one hour afterwards, the ship's position was again found in similar manner, and, when compared with the run by log and course steered in the interval, shewed the set of tide to be N. 70° E. (true), and rate 3 knots.

* See Appendix M.

CHAPTER XIX.

THE COMPOSITION AND RESOLUTION OF FORCES AND VELOCITIES.

A full understanding of the Composition and Resolution of Forces and Velocities is of so much importance to the sailor, from the infinite number and diversity of their application to *every* branch of his business, that it is hoped the introduction of a chapter, savouring at first sight more of mechanics than navigation, will not be considered out of place. Indeed, there are few problems in physical science with which the principles herein to be explained are not intimately blended. Their relation to navigation, generally, is close; but it is seen more particularly, perhaps, in *Current Sailing*, and also when it becomes necessary to trace the total effect on the compasses of an iron ship to its various causes.

Knowledge of this subject very important to seamen.

Motion is the direct outcome of *force*, and the composition and resolution of *motions* are in all respects analogous to those of *forces*. It is therefore quite admissible, and will be convenient here, to deal with them as synonymous or convertible terms.

Motion and Force.

A single force may be represented on paper by an arrow-headed straight line: the commencement of the line indicating the *Point of application* of the force; the direction of the line, the *Direction* of the force; and the length of the line, the *Magnitude* or *Intensity* of the force, according to the scale made use of.

A Single Force, how represented on paper.

The smallest number of *inclined* forces which can maintain equilibrium is three. To do so, these three forces must act through one point, and in one plane. Their relation to each other depends on the following principle in mechanics, known as the *Parallelogram of Forces*, or, where motion is alluded to, as the *Parallelogram of Velocities*. The law is thus expressed. If two forces be represented in magnitude and direction by the adjacent sides of a parallelogram an *equivalent* force will be represented in magnitude and direction by that diagonal, which

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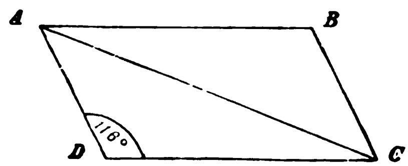
Parallelogram of Forces and Velocities.

passes through the point of intersection of those two sides. The two side forces are termed the *Components;* and the diagonal is the *Resultant* of their joint effort; while the point where all three act is called the *Point of application.*

Parallelograms

A parallelogram is a four-sided, straight-lined figure, the opposite sides of which are parallel; and the diameter, or diagonal, is the straight line joining two of its opposite angles. The square, the oblong, the rhombus, and the rhomboid are four different kinds of parallelograms. In the first, all the sides are equal, and all the angles are right angles; the second has all its angles right angles, but all its sides are not of the same length; the third has all its sides equal, but its angles are not right angles; and the fourth has only its opposite sides of the same length, and its angles are not right angles.



In the rhomboid here given, the side AB is parallel to the side CD, and AD is parallel to BC. The angle BAD is equal to the angle BCD; the angle ABC is equal to the angle ADC; and AC is one diagonal. If AB and AD represent two forces in magnitude and direction, then AC represents their resultant, and A is the point of application.

Given one angle in a parallelogram to find the other three.

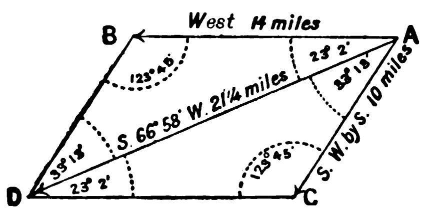
In any parallelogram the four angles amount to four right angles, or 360°; and, from the fact, above stated, that any two diagonally opposite angles are equal to each other, if *one* angle be given, *the other three* can easily be determined. Thus, if ADC = 116°, the angle ABD will also equal 116°. These two values added together, and the sum subtracted from 360°, leaves 128° as the sum of BAD and BCD; and, as these are equal each to the other, their values must be respectively half of 128°, or 64°. Again, the two interior angles on the same side of either AB or BC are together equal to two right angles; therefore, to find the value of the angle BCD, we simply subtract the number of degrees in ABC from 180°. Hence, BCD = 180° − ABC = 180° − 116° = 64°, thus confirming the result of the previous method. By drawing a parallelogram on paper, and measuring the angles by protractor, it will be found that these rules are universally true. It is well to alter the lettering of the angles, to ensure familiarity with the methods employed, of any geometrical figure.

Composition of Velocities.

The following is an example of the Composition of Velocities, which should be mastered by every seaman.

In a calm, the onward progress of a steamship causes those on board of her to experience a breeze, which would appear to come from right ahead at a rate exactly equal to the speed of the ship over the ground. In the accompanying figure let AB represent the apparent wind, due to the advance of a steamer steering due East, 14 miles an hour; and let AC represent the true wind such as would be experienced by the vessel if stopped, say from N.E. by N., 10 miles an hour. Then AB, AC, are the two components of the resultant AD, found by completing the parallelogram ABDC; and AD represents the direction and the velocity of the wind as felt by an observer on deck, due to

Scale: 1 inch = 10 miles.



the combined directions and velocities of the actual wind and of the ship's advance. To solve by construction is far from difficult! Let A be the ship's position; draw AB in a direction due West from A, make AB = 14; and draw AC in a S.W. by S. direction, making AC = 10. Complete the parallelogram ABDC, and join AD; then AD represents in magnitude and direction, on the same scale as the other lines, the resultant wind, which is N. 66° 58′ E., 21¼ miles an hour. Check this by protractor and a pair of compasses! "See everything as you pass it" is a rule that holds in mathematics quite as much as it does in the coasting trade.

In order to calculate the direction and velocity of the resultant, we have, in the figure, CD = AB, and AC = BD. Moreover, the angle BAC is included between the bearings West and S.W. by S.; and is, therefore, 5 points, or 56° 15′. Hence, from what has gone before, the angle ACD = 180° − 56° 15′ = 123° 45′; and, in the triangle ACD, there are given the two sides AC, CD, and the included angle ACD, to find AD. A reference to any book on plane trigonometry will disclose the formulæ used in the following solution.

$$\text{CD} + \text{AC} : \text{CD} - \text{AC} :: \tan. \frac{\text{DAC} + \text{ADC}}{2} : \tan. \frac{\text{DAC} - \text{ADC}}{2} \qquad (1)$$

$$\text{Sin. ADC} : \text{sin. ACD} :: \text{AC} : \text{AD} \qquad (2)$$

CD . . = 14	DAC + ADC = 180° − 123° 45′ . . = 56° 15′
AC . . = 10	½ (DAC + ADC) . . . . = 28° 7½′
—	½ (DAC − ADC) . . . . = 5° 5½′
Sum . . = 24	
—	∴ DAC = 33° 13′, and ADC = 23° 2′
Difference = 4	

To Find ½ (DAC − ADC).		To Find AD.	
4 log.	0·6020	ACD sin.	9·9198
28° 7½′ tan. . . .	9·7280	AC log.	1·0000
	0·3300		0·9198
24 log.	1·3802	ADC sin.	9·5925
5° 5½′ tan.	8·9498	21·25 log.	1·3273
∴ ½ (DAC − ADC) = 5° 5½′		∴ AD = 21¼	

Inspection by aid of traverse table, however, will suit every case admirably; although undue reliance upon short cuts of this nature tends to reduce the navigator to the low plane of a mechanical computer. Here we may regard the problem from the point of view of a vessel steaming first S.W. by S. 10 miles and then W. 14 miles, to find the course and distance made good in the usual way.

Co.	Dist.	N.	S.	E.	W.
S. 3 pts. W.	10	—	8·3	—	5·6
W.	14	—	—	—	14·0
S. 66° 58′ W.	21¼	—	8·3	—	19·6

Hence, the supposititious ship having made S. 66° 58′ W., the resultant of the actual wind and the actual ship's travel is as though the wind blew from N. 66° 58′ E., at the rate of 21¼ miles an hour. A ship under the influence of a sea-surface current affords a similar example, to be worked in the same way, for each method; and, just as the azimuth table provides an infinite number of problems in great circle sailing, so the traverse table may be pressed into the service of workers, when remote from teachers, for problems in plane trigonometry.

Composition of more than two Forces, or Velocities.

Knowing how to compound two forces, or two velocities, acting at a point, it is easy to compound, or determine the resultant of, any number of forces acting at a point, by taking them in detail. Compound the resultant of two with a third force, then compound this resultant with a fourth force, and so on until but one resultant is left. This method, as will be seen by the seaman, is on all fours with that employed when solving a day's work of many courses and distances by traverse table.

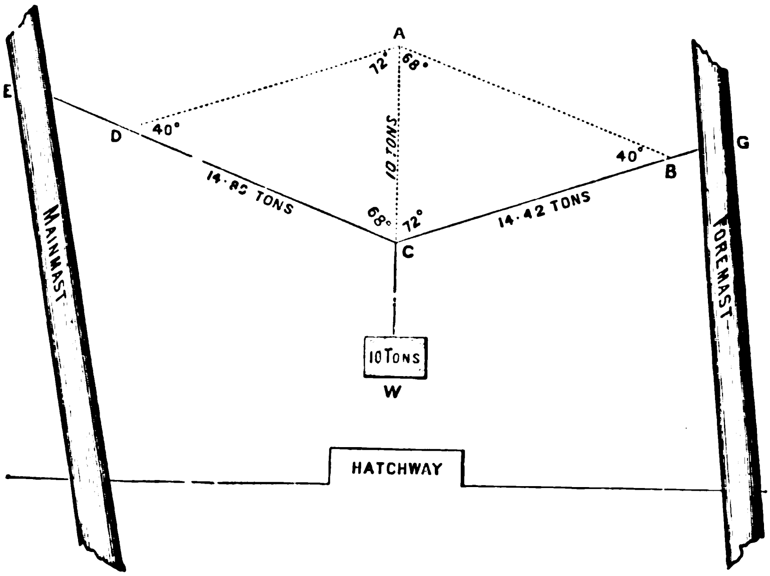
Resolution of Forces, or Velocities.

The *Resolution of Forces*, or of *Velocities*, is the converse of the foregoing example. To resolve, or split up as it were, a given force, or a given velocity, into its components, let AD represent the force, or velocity, in magnitude and direction. Then we have merely to draw a parallelogram having AD as diagonal, and AB, AC, will similarly represent the required components, respectively, in magnitude and in direction.

It is evident that there are an infinite number of pairs of forces into which BD might be resolved. It is usual, however, to resolve a force into forces that are at right angles to each other.

Subjoined is one more example of the practical value of understanding the *Parallelogram of Forces.*

Important illustration shewing how strains can be calculated.



"Stand from under."

In the diagram, W is a weight of ten tons which is suspended without motion from a span between two masts. Let the angle DCB = 140°, and the angle ACB = 72°, then the angle ACD will = 68°.* Draw AC to represent 10 tons on any convenient scale, say a tenth of an inch to the ton; also draw AB parallel to DC, and AD parallel to BC. Then by simple proportion of the parts, DC will represent the strain on the after pennant = 1·480 inches by scale, or 14·80 tons; and CB the strain on the forward pennant = 1·442 inches by scale, or 14·42 tons.

In triangle ACD we have AC = 10, CAD = 72°, ADC = 40°, to find CD.

$$\text{Formula: } \frac{\text{CD}}{\text{AC}} = \frac{\text{sin. CAD}}{\text{sin. ADC}} \therefore \text{CD} = \text{AC}\,\frac{\text{sin. CAD}}{\text{sin. ADC}}$$

But to divide by the sine is equivalent to multiplying by the cosecant; and we may write, in order to lessen the treadmill work,

$$\begin{aligned} \text{CD} &= \text{AC sin. CAD cosec. ADC} \\ &= 10 \text{ sin. } 72^\circ \text{ cosec. } 40^\circ \end{aligned}$$

Similarly, in triangle ABC, we have AC = 10, BAC = 68°, ABC = 40°, to find CD; and, by the same formula as above,

$$\begin{aligned} \text{BC} &= \text{AC sin. BAC cosec. ABC} \\ &= 10 \text{ sin. } 68^\circ \text{ cosec. } 40^\circ \end{aligned}$$

To Find CD.		To Find BC.	
10 log.	1·00000	10 log.	1·00000
72° sin.	9·97821	68° sin.	9·96717
40° cosec.	0·19193	40° cosec.	0·19193
CD log.	1·17014	BC log.	1·15910
	∴ CD = 14·8		∴ BC = 14·42

Hence, strain on CD is 14·8 tons; and on BC is 14·42 tons.

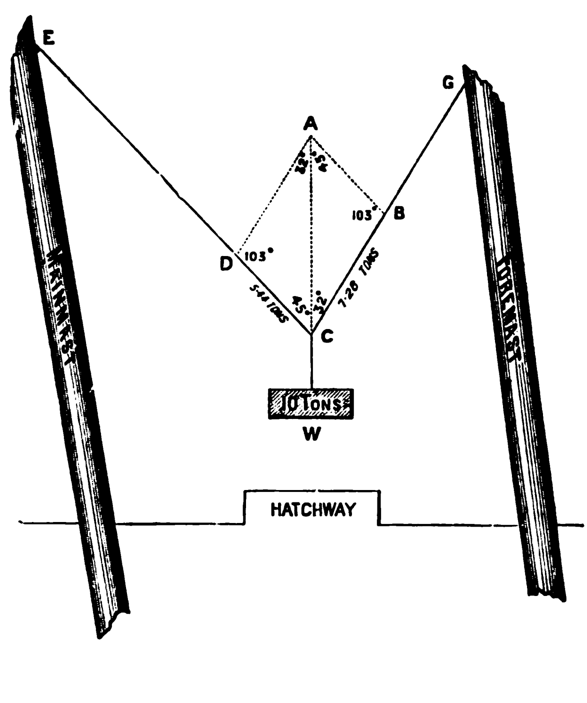
Similarly, having ascertained the strain on the pennants, it is easy, by constructing other two parallelograms, to calculate the "up and down," or crushing strain on each mast, as well as the bending, or exact, "fore-and-aft" pull.

* The Euclid scholar will have no difficulty in seeing how the values of the remaining angles are arrived at, but for the information of such as are weak in geometry, be it known that in any parallelogram the angle DAC will always be equal to its counterpart ACB, in this case 72°. The three angles of a triangle when added together make exactly 180°, so that if two are known, the third is easily found. Then ACD + DAC, or 68° + 72° = 140°, which subtracted from 180°, gives the angle ADC as 40°, and since according to the definition of a parallelogram the angle ADC is equal to its opposite angle ABC, the latter must be equal to 40° also.

In the foregoing example—common enough on board ship—the strain on each of the two parts of the span is shewn to be something excessive—much more so, indeed, than one would at first sight conceive to be possible, and this, too, without taking into account the additional strain which the span would have to sustain were it required to *lift* the weight instead of merely *suspending* it, as in the diagrams.

This example, though not pertaining to Navigation, is specially introduced because of its exceeding value in putting the sailor on his guard as to the peculiar properties of a span in connection with the dangerous operation of taking heavy weights in or out. The flatter the span, the greater will be the breaking or tensile strain it will have to endure, and the greater also will be the bending or shearing strain upon the masts. Therefore, when practicable, make it a rule to have the parts as much "up and down" as the drift necessary to clear the hatchway and bulwarks will admit of. **Flat Cargo Spans.**

We will now try what stress the span would have to bear, supposing the weight still the same, but the angle DCB *acute*, instead of *obtuse* as before.



Let the angle BCD = 77°, and the angle ACB = 32°, then the angle ACD = 77° − 32° = 45°. The remaining angles are obtained as already explained; and the solution follows that of the preceding example.

To Find CD.		To Find BC.	
10 log.	1·00000	10 log.	1·00000
32° sin.	9·72421	45° sin.	9·84949
103° cosec. . . .	0·01128	103° cosec. . . .	0·01128
CD log.	0·73549	BC log.	0·86077
∴ CD =	5·44	∴ BC =	7·26

Hence, the strain on CD is 5·44 tons; and on BC is 7·26 tons.

We here see that the strain on the span is positively much *less than half what it was in the first case*, shewing very clearly the impropriety of rigging cargo gear straight across from mast to mast. Through pure ignorance of the danger incurred, this arrangement is quite common, as one may find out for himself by taking the trouble to walk round the docks of any large port. The consequences are seen in loss of life, broken spars, and claims for smashed up cargo. These evidences of grievous ignorance occur more frequently than one would imagine. The writer recollects the case, not so very long ago, of two celebrated steamers belonging to the same owners, where, through this cause, the masts were brought down on deck when taking out their funnels, though the heavier funnel of the two had but the paltry weight of four tons!!! Yet later, the taking out of a crank-shaft in a certain vessel had a similar result.

Lubberly accidents.

As an illustration familiar to every seaman take this one:— When a weak-handed watch can get no more of a rope (say the lee fore-brace) by straight pulling on it, what do they do? Why, make it fast to the pin and "swig it off." By so doing they are unconsciously acting the part of the weight on a straight span. The belaying pin may be taken to represent one mast, the leading block the other, and the part of the brace between these two points as the span. So powerful is the effect that the invariable result is to gain more of the brace after total failure to do so in the ordinary way.

"Swigging off" a rope.

There is scarcely a limit to the application of this important principle in the science of Forces. It comes into play in a marked manner in the case of a vessel riding to two anchors— one broad on each bow. The proof is easy that when the

Disposition of anchors in a gale.

spread is great, two anchors, so placed, are actually weaker to hold the vessel in a gale than one anchor right ahead.

The Traverse Table can often be taken advantage of to solve problems similar to those given in this chapter. In fact, the Traverse Table is a "handy-billy" in much trigonometrical work involving a right angle.

"Forces and Velocities" remind one of the tables frequently seen in pocket-books, which assign a pressure and velocity to the wind. Such tables should be received with great caution—firstly, because there is a doubt as to the accuracy of the instruments which record wind velocity; secondly, because there is a further doubt as to the relation between velocity and pressure; and, thirdly, because the pressure is supposed to vary as the square of the velocity, so that any error in the estimate of the latter becomes greatly exaggerated when turned into pressure. **Wind measurement**

CHAPTER XX.

ALGEBRA.

Algebra is usually a great bugbear to sailors, and although in the Practice of Navigation it cannot be considered an *essential*, a knowledge of the first four rules will occasionally be found very useful indeed. And these rules are so simple, that to commit them to memory within an hour or two need not "pawl the capstan" of anyone possessing average intelligence. They are here given for reference when wanted.

ALGEBRAIC ADDITION.

Positive quantities added together give a *positive* result.

EXAMPLE.

$$\begin{array}{lr} & +2 \\ \text{Added to} & +4 \\ \hline \text{Equal} & +6 \end{array}$$

Negative quantities added together give a *negative* result.

EXAMPLE.

$$\begin{array}{lr} & -2 \\ \text{Added to} & -4 \\ \hline \text{Equal} & -6 \end{array}$$

To add together *unlike* quantities, take their difference, and prefix the sign of the greater.

EXAMPLE.

$$\begin{array}{lr} & -2 \\ \text{Added to} & +4 \\ \hline \text{Equal} & +2 \end{array}$$

ALGEBRAIC SUBTRACTION.

To subtract one quantity from another, change the sign of the quantity to be subtracted, take their difference, and affix the sign of the greater, *if they are then of opposite names;* but if changing the sign of the subtrahend, make it similar to that of the minuend, then add arithmetically both quantities together, and prefix the same (or common) sign.

EXAMPLES.

From	-4	From	-4
Subtract	-2 (change the sign)	Subtract . . .	$+2$ (change the sign)
Remains . . .	-2	Remains . . .	-6

ALGEBRAIC MULTIPLICATION.

Like signs give +, and *unlike* signs give −.

EXAMPLES.

If	-4	If	$+4$	If	$+4$	If	-4
Be multiplied by	-2	Be multiplied by	$+2$	Be multiplied by	-2	Be multiplied by	$+2$
The product equals	$+8$	The product equals	$+8$	The product equals	-8	The product equals	-8

ALGEBRAIC DIVISION.

When the Divisor and Dividend have *like* signs, the sign of the quotient is plus; and when the signs are *unlike,* that of the quotient is minus.

EXAMPLES.

$-2)-4(+2$	$+2)+4(+2$	$-2)+4(-2$	$+2)-4(-2$
-4	$+4$	$+4$	-4

DOMINO.

APPENDIX.

(A).

On the method of correcting the rate of a Marine Chronometer.

When the mean rates which a chronometer has made in the three temperatures, 55°, 70°, and 85°, are known from the Observatory rate sheets, it is necessary to calculate the quantities, C, T, and R, for that watch.

T is the temperature in which the watch attains its maximum gaining rate.

R is the rate at T.

C is a constant factor, which, multiplied by the square of any number of degrees from T, shows the amount of loss for that number of degrees.

It may be here mentioned that C and T have been found by experiment to remain constant for long periods, seldom changing, unless the watch is either cleaned or repaired. R, on the contrary, is liable to change occasionally, and should be verified at every opportunity of obtaining a rate by observation.

Formula for finding C, T, and R.*

Rate in 55° say $-\ 0{\cdot}72^s \ldots r$

$\ldots r - r' = -\ 0{\cdot}45 \ldots d$

" 70° " $-\ 0{\cdot}27^s \ldots r'$

$\ldots r' - r'' = +\ 1{\cdot}08 \ldots d'$

" 85° " $-\ 1{\cdot}35^s \ldots r''$

$d - d' = -\ 1{\cdot}53$

$d + d' = +\ 0{\cdot}63$

To find C

$$C = \frac{2\,(d - d')}{30^2} = \frac{-\ 3{\cdot}06}{900} = -\ 0{\cdot}0034$$

---

* Sign + indicates fast error, or gaining rate

" − " slow " or losing "

To find T

$$(T - 70°) = \frac{d + d'}{C \times 60} = \frac{+ 0{\cdot}63}{- 0{\cdot}204} = - 3{\cdot}1°$$

$$\therefore\ T = 70° - 3{\cdot}1° = 66{\cdot}9°$$

$$(T - 70)^2 \times C = 9{\cdot}61 \times 0{\cdot}0034 = 0{\cdot}03^{s.}$$

To find R

Rate at . 70°	= − $0{\cdot}27^{s.}$	losing.
Difference to T	= + $0{\cdot}03^{s.}$	faster.
R	= − $0{\cdot}24^{s.}$	losing.

Let . . N = any number of degrees from T.
Then $C \times N^2$ = amount of loss for N.

The quantities C, T, and R, for any watch, having been found, the rule for finding the rate of the same watch in any given temperature is as follows:—

Take the difference between the given temperature and T (calling this difference N).

Multiply N^2 by C, and the result will be the amount by which the watch will go slower at the given temperature than it does at T; and, therefore, by applying the amount thus obtained to R (the rate of the watch at T), the rate in the given temperature will be obtained.

When C, T, and R have been found, the rate which the watch will keep in various temperatures can be found from the Table on next page but one.

The Table gives the amount by which a watch will go slower than at T, at any given number of degrees from T. The rule for using the Table is:—

Take the difference between the given temperature and T (that is, N).

Take C to the nearest third decimal place. Enter the Table with C at the head. Enter the column marked N, with N as given to nearest degree, and in the column marked Cor'n will be found the amount by which the watch will go slower for N degrees.

Example:—

T 72° C 0·003 R − $0{\cdot}54^{s.}$

Required the rate in 60°.
Difference between T and given temperature = 12° = N.
Enter Table headed C 0·003, and column N, and take 12°.
The column headed Cor'n gives − $0{\cdot}43^{s.}$ losing.

	R − 0·54	−
Rate in 60° .	− $0{\cdot}97^{s.}$	

The "thermal error" or correction of the rates for temperature, as carried out at the Bidston Observatory, has led to the discovery by Mr. Hartnup of a small but very systematic difference between the "Sea" and "Shore" rates of chronometers. With very few exceptions, chronometers used in steamships have been found to go somewhat *slower* at sea than on shore—the amount in different instruments ranging from a small fraction of a second to upwards of one second a day. This is probably caused by the motion of the ship, or the magnetic effect of the metal of which she is built. It is small in comparison with the thermal error, and is only capable of being detected in cases where the corrections for change of temperature have been carefully applied at sea during the voyage.

Since the above was written, radio-telegraphy, popularly known as wireless, has become an accomplished fact between ship and shore. Time signals are sent seaward daily from the United States Naval Wireless Telegraphic Stations at short intervals; received by ships within the effective radius, that are fitted with radio-telegraphic installation which is in working order, and used for verifying or correcting chronometer rates, and hence the time and longitude at sea. The French Government similarly despatch wireless time signals, for chronometer purposes, from Eiffel Tower, Paris, to ships in the vicinity that are fitted with wireless installation. Such an easy and reliable system of determining Greenwich Mean Time has been underway since 1910, and was fully described on the United States Hydrographic Office Pilot Charts of January, 1911. During the war wireless time signals from Eiffel Tower have been discontinued.

TABLE OF CORRECTIONS DUE TO CHANGES OF TEMPERATURE.

C 0·001.

N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.
	s.		s.		s.		s.		s.
1	0·00	21	0·44	41	1·68	61	3·72	81	6·56
2	0·00	22	0·48	42	1·76	62	3·84	82	6·72
3	0·01	23	0·53	43	1·85	63	3·97	83	6·89
4	0·02	24	0·58	44	1·94	64	4·10	84	7·06
5	0·02	25	0·62	45	2·02	65	4·22	85	7·22
6	0·04	26	0·68	46	2·12	66	4·36	86	7·40
7	0·05	27	0·73	47	2·21	67	4·49	87	7·57
8	0·06	28	0·78	48	2·30	68	4·62	88	7·74
9	0·08	29	0·84	49	2·40	69	4·76	89	7·92
10	0·10	30	0·90	50	2·50	70	4·90	90	8·10
11	0·12	31	0·96	51	2·60	71	5·04	91	8·28
12	0·14	32	1·02	52	2·70	72	5·18	92	8·46
13	0·17	33	1·09	53	2·81	73	5·33	93	8·65
14	0·20	34	1·16	54	2·92	74	5·48	94	8·84
15	0·22	35	1·22	55	3·02	75	5·62	95	9·02
16	0·26	36	1·30	56	3·14	76	5·78	96	9·22
17	0·29	37	1·37	57	3·25	77	5·93	97	9·41
18	0·32	38	1·44	58	3·36	78	6·08	98	9·60
19	0·36	39	1·52	59	3·48	79	6·24	99	9·80
20	0·40	40	1·60	60	3·60	80	6·40	100	10·00

C 0·002.

N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.
	s.		s.		s.		s.		s.
1	0·00	21	0·88	41	3·36	61	7·44	81	13·12
2	0·01	22	0·97	42	3·53	62	7·69	82	13·45
3	0·02	23	1·06	43	3·70	63	7·94	83	13·78
4	0·03	24	1·15	44	3·87	64	8·19	84	14·11
5	0·05	25	1·25	45	4·05	65	8·45	85	14·45
6	0·07	26	1·35	46	4·23	66	8·71	86	14·79
7	0·10	27	1·46	47	4·42	67	8·98	87	15·14
8	0·13	28	1·57	48	4·61	68	9·25	88	15·49
9	0·16	29	1·68	49	4·80	69	9·52	89	15·84
10	0·20	30	1·80	50	5·00	70	9·80	90	16·20
11	0·24	31	1·92	51	5·20	71	10·08	91	16·56
12	0·29	32	2·05	52	5·41	72	10·37	92	16·93
13	0·34	33	2·18	53	5·62	73	10·66	93	17·30
14	0·39	34	2·31	54	5·83	74	10·95	94	17·67
15	0·45	35	2·45	55	6·05	75	11·25	95	18·05
16	0·51	36	2·59	56	6·27	76	11·55	96	18·43
17	0·58	37	2·74	57	6·50	77	11·86	97	18·82
18	0·65	38	2·89	58	6·73	78	12·17	98	19·21
19	0·72	39	3·04	59	6·96	79	12·48	99	19·60
20	0·80	40	3·20	60	7·20	80	12·80	100	20·00

C 0·003.

N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.
	s.		s.		s.		s.		s.
1	0·00	21	1·32	41	5·04	61	11·16	81	19·68
2	0·01	22	1·45	42	5·29	62	11·53	82	20·17
3	0·03	23	1·59	43	5·55	63	11·91	83	20·67
4	0·05	24	1·73	44	5·81	64	12·29	84	21·17
5	0·08	25	1·88	45	6·08	65	12·68	85	21·68
6	0·11	26	2·03	46	6·35	66	13·07	86	22·19
7	0·15	27	2·19	47	6·63	67	13·47	87	22·71
8	0·19	28	2·35	48	6·91	68	13·87	88	23·23
9	0·24	29	2·52	49	7·20	69	14·28	89	23·76
10	0·30	30	2·70	50	7·50	70	14·70	90	24·30
11	0·36	31	2·88	51	7·80	71	15·12	91	24·84
12	0·43	32	3·07	52	8·11	72	15·55	92	25·39
13	0·51	33	3·27	53	8·43	73	15·99	93	25·95
14	0·59	34	3·47	54	8·75	74	16·43	94	26·51
15	0·68	35	3·68	55	9·08	75	16·88	95	27·08
16	0·77	36	3·89	56	9·41	76	17·33	96	27·65
17	0·87	37	4·11	57	9·75	77	17·79	97	28·23
18	0·97	38	4·33	58	10·09	78	18·25	98	28·81
19	1·08	39	4·56	59	10·44	79	18·72	99	29·40
20	1·20	40	4·80	60	10·80	80	19·20	100	30·00

C 0·004.

N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.
	s.		s.		s.		s.		s.
1	0·00	21	1·76	41	6·72	61	14·88	81	26·24
2	0·02	22	1·94	42	7·06	62	15·38	82	26·90
3	0·04	23	2·12	43	7.40	63	15·88	83	27·56
4	0·06	24	2·30	44	7·74	64	16·38	84	28·22
5	0·10	25	2·50	45	8·10	65	16·90	85	28·90
6	0·14	26	2·70	46	8·46	66	17·42	86	29·58
7	0·20	27	2·92	47	8·84	67	17·96	87	30·28
8	0·26	28	3·14	48	9·22	68	18·50	88	30·98
9	0·32	29	3·36	49	9·60	69	19·04	89	31·68
10	0·40	30	3·60	50	10·00	70	19·60	90	32·40
11	0·48	31	3·84	51	10·40	71	20·16	91	33·12
12	0·58	32	4·10	52	10·82	72	20·74	92	33·86
13	0·68	33	4·36	53	11·24	73	21·32	93	34·60
14	0·78	34	4·62	54	11·66	74	21·90	94	35·34
15	0·90	35	4·90	55	12·10	75	22·50	95	36·10
16	1·02	36	5·18	56	12·54	76	23·10	96	36·86
17	1·16	37	5·48	57	13·00	77	23·72	97	37·64
18	1·30	38	5·78	58	13·46	78	24·34	98	38·42
19	1·44	39	6·08	59	13·92	79	24·96	99	39·20
20	1·60	40	6·40	60	14·40	80	25·60	100	40·00

C 0·005.

N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.	N.	Cor'n.
	s.		s.		s.		s.		s.
1	0·00	21	2·20	41	8·40	61	18·60	81	32·80
2	0·02	22	2·42	42	8·82	62	19·22	82	33·62
3	0·04	23	2·64	43	9·24	63	19·84	83	34·44
4	0·08	24	2·88	44	9·68	64	20·48	84	35·28
5	0·12	25	3·12	45	10·12	65	21·12	85	36·12
6	0·18	26	3·38	46	10·58	66	21·78	86	36·98
7	0·24	27	3·64	47	11·04	67	22·44	87	37·84
8	0·32	28	3·92	48	11·52	68	23·12	88	38·72
9	0·40	29	4·20	49	12·00	69	23·80	89	39·60
10	0·50	30	4·50	50	12·50	70	24·50	90	40·50
11	0·60	31	4·80	51	13·00	71	25·20	91	41·40
12	0·72	32	5·12	52	13·52	72	25·92	92	42·32
13	0·84	33	5·44	53	14·04	73	26·64	93	43·24
14	0·98	34	5·78	54	14·58	74	27·38	94	44·18
15	1·12	35	6·12	55	15·12	75	28·12	95	45·12
16	1·28	36	6·48	56	15·68	76	28·88	96	46·08
17	1·44	37	6·84	57	16·24	77	29·64	97	47·04
18	1·62	38	7·22	58	16·82	78	30·42	98	48·02
19	1·80	39	7·60	59	17·40	79	31·20	99	49·00
20	2·00	40	8·00	60	18·00	80	32·00	100	50·00

APPENDIX (B).

It has been considered advisable to give a place to the following correspondence between the author and another, bearing as it does upon a very important consideration in the navigation of iron ships:—

The Editor, Mercantile Marine Service Association "Reporter."

HEELING ERROR.

Sir,—Will any correspondent kindly give the method usually employed at the Board of Trade Examinations for calculating the Heeling Error? Given the heel, the direction of the ship's head by compass, and the Heeling Error observed, to find the approximate Heeling Error, with a greater or less given heel, and with the ship's head on some other named point of the compass, the ship's magnetic latitude being in both cases the same.—Yours faithfully, INGANNO.

December, 1877.

The Editor, Mercantile Marine Service Association "Reporter."

HEELING ERROR.

Sir,—In answer to "Inganno," in your January number, I submit that the first thing to be done is to determine what is called the *heeling co-efficient.* It is the error on the North or South point *by compass*, caused by *one* degree of heel, and is found by dividing the difference between the deviation, ship upright and ship heeling, by the number of degrees of heel.

For example, given the deviation on North, ship upright, equal to $-21°$; when heeling 12° to starboard, equal to $-3°$; this is equivalent to a *plus* change of 18°, which, divided by 12° of heel, gives $+1°\cdot5$ as the *heeling co-efficient* for each degree of heel to starboard. From this it will be seen that the heeling error is *directly proportional* to the amount of heel. Now, when the heeling error is given for any other than the North or South points, it is easily reduced to these by simply dividing it by the natural cosine of the number of points from North or South; then divide the result by the inclination to starboard or port, as the case may be, and you have the *heeling co-efficient* as before.

For example, the heeling error on W.N.W., with 16° of heel to port, is $-9°{\cdot}19$; divide this by ·383 (the natural cosine of 6 points) and you get 24°; divide this by the heel (16°), and once again we shake hands with our friend the *heeling co-efficient.*

Now it is evident that if we require the heeling error for any other given point, we have merely to *multiply the heeling co-efficient* by the natural cosine of the number of points contained between North *or* South (taking the nearest) and the stated point, multiply the result by the fresh heel, and we have the error required.

For example, the *heeling co-efficient* on North is $+1°{\cdot}5$ for each degree of heel to starboard; required the heeling error on N.E. by N. ½ N., heeling 10° to starboard. Multiply $+1°{\cdot}5$ by ·882 (the natural cosine of 2½ points): the result is $+1°{\cdot}32$; multiply this again by 10° inclination to starboard, and we get $+13°{\cdot}23$ as the answer.

I have treated the foregoing solution of the question asked by "Inganno" at considerable length, and in piecemeal fashion, hoping that by so doing it would be rendered clearer. The mathematical expression is very concise, but seamen are more accustomed to regard *weather* signs than to study *algebraic* ones. Before quitting this subject I must warn "Inganno" that if the heeling error has a *plus* sign when heeling to starboard, it will have a *minus* one with a heel in the opposite direction; also, that the signs are reversed when the Northern semicircle of the compass is substituted for the Southern one, or the contrary. For example, if the *heeling co-efficient* on North is $+1°{\cdot}5$ when heeling to starboard, it will be $-1°{\cdot}5$ on South when heeling the same way. In conclusion, the *heeling error* on any given point must not be confounded with the *deviation* on the same point. For example, the *deviation*, ship upright on S.W. is + 13°, but when heeling 17° to port it is only + 2°, the heeling error is consequently − 11°.

COMPLETE EXAMPLE.—With ship's head S.E. by E., and upright, the deviation is + 23°; when heeling 8° to port it is + 3°. Required the deviation on N.N.W., when heeling 15° to starboard; the deviation on that point, when upright, being − 14°; magnetic latitude the same in each case? Answer, $-76°{\cdot}25$.

SQUIRE T. S. LECKY.

February 20th, 1878.

APPENDIX (C).

STAR TELESCOPE FOR SEXTANTS.

About the first thing to be seen to on getting a star telescope fitted to one's sextant, is that its collimation adjustment is perfect. If the line of sight of the telescope is at all inclined to the plane of the instrument, instead of being strictly parallel to it, as it should be, all angles measured with it will be too great; and the larger the angle so measured, the greater will be the error. To determine the value of the error corresponding to the various angles or altitudes, which may at any time be observed, proceed as follows:—The sextant being in perfect adjustment, screw in the ordinary direct telescope, and, on a fine clear night, measure carefully the angle between two stars, whose distance apart is between 100° and 110°. Read off and note this angle, but do not move the index; then insert the star telescope, and verify the measure—*taking care to make it in the very centre of the field.* If the line of collimation is correct, the stars will be in contact as before; but if it is not so, the stars will appear to have separated. Bring them again into contact, and, having read off the angle, the difference between it and the first reading is, of course, the error for that particular angle.

To find what it would be for smaller angles, one might proceed as before, by selecting stars at the required distance apart; but it is better to adopt another method, wherein a knowledge of the error of parallelism of the telescope is pre-supposed.

Raper, in his explanation to Table 54, already referred to on page 73, gives a rule for determining the error for any given altitude or angular distance when the error of parallelism of the telescope employed is known; and this same rule, *when worked backwards*, serves of course to find the error of parallelism.

Rule to find the Error of Parallelism.

From the log. sine of the error belonging to any given angle, measured by sextant, subtract the log. tangent of half the same angle, and the remainder divided by 2 will be the log. sine of the error of collimation.

Example.

Let the error at 100° due to defective adjustment of the line of collimation be 8′; required the inclination of the telescope to the plane of the sextant.

Log. sine of 8′	7·36682
Log. tangent of half 100° = 50°	10·07619
2	17·29063
Log. sine 2° 32′......................	8·64531

Now, having ascertained the angular inclination of the telescope to the plane of the sextant, if it be required to know the quantity to be subtracted from any other altitude or distance measured with the same star telescope and sextant, we must employ Raper's rule in its direct form as follows:—

"To twice the log. sine of the error in the parallelism of the telescope, add the log. tangent of *half* the angle measured. The sum will be the log. sine of the required error in the observed angle."

Example.

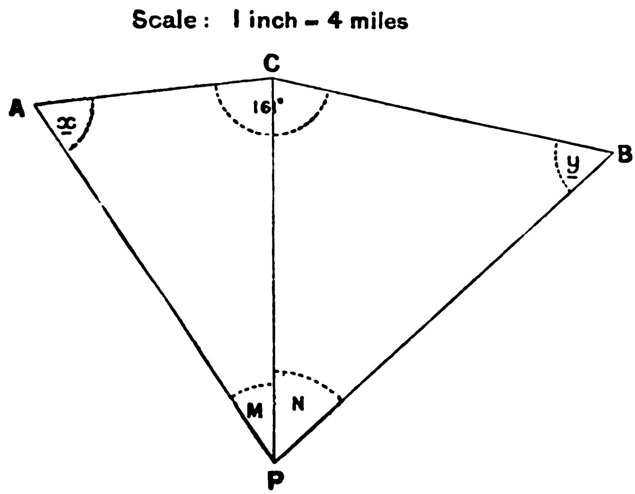
The error of parallelism having been determined as 2° 32′, required to know the quantity to be subtracted from an observed altitude of 40°.

2° 32′ Log. sine 8·64531 × 2	7·29062
Half of 40° = 20° Tangent	9·56107
Quantity to be subtracted 2′ 27″ Sine ...	6·85[illegible]59

Having ascertained by *direct measurement* the error at 100° or thereabouts, it is recommended to ascertain, by *calculation* as above, the error for all other altitudes at intervals of say 5°. Having thus made a small table, gum it on the inside of the lid of the sextant case for ready reference. Whether the errors are known or not, don't forget the advice on page 376, to observe stars on *both sides of the zenith*. The diameter of the object glass of the star telescope should not exceed 1⅝ inches clear aperture, unless special provision is made for one of greater size by raising the horizon-glass an additional $\frac{3}{16}$ of an inch or thereabouts above the plane of the instrument. *In using the star telescope be careful to observe as nearly as possible in the exact centre of the field.*

APPENDIX (D).

THE THREE POINT PROBLEM



Let the unknown angle at A be x, and the angle at B be y. Then x and y may be found, as follows, by the algebraical artifice of the employment of an auxiliary angle, here called θ. In any plane triangle we have the sides proportional to the sines of the opposite angles, as proved in works on Plane Trigonometry. Hence, in the triangles APC, BPC, it follows that:

$$\frac{\sin. x}{\sin. M} = \frac{CP}{AC} \ (1); \quad \text{and} \quad \frac{\sin. y}{\sin. N} = \frac{CP}{BC} \quad (2)$$

$$\therefore CP = \frac{AC \sin. x}{\sin. M} \ (1); \quad \text{and } CP = \frac{BC \sin. y}{\sin. N} \ (2)$$

but things that are equal to the same thing are equal each to the other:

$$\therefore \frac{AC \sin. x}{\sin. M} = \frac{BC \sin. y}{\sin. N}$$

$$\text{and } \therefore \frac{\sin. x}{\sin. y} = \frac{BC \sin. M}{AC \sin. N}$$

and the right hand side of this last equation may be assumed, correctly, to be equal to the tangent of auxiliary angle θ; because the tangent of an angle varies through every value from zero to infinity, plus or minus.

$$\therefore \frac{\sin. x}{\sin. y} = \frac{BC \sin. M}{AC \sin. N} = \tan. \theta$$

Then, by subtracting and adding unity to each side of this equation, and dividing out, we get:

$$\frac{\sin. x - \sin. y}{\sin. x + \sin. y} = \frac{\tan. \theta - 1}{\tan. \theta + 1}$$

and a reference to any work on Plane Trigonometry shews that this equation may be written in the more convenient form for logarithmic calculation:

$$\frac{\tan. \frac{1}{2}(x - y)}{\tan. \frac{1}{2}(x + y)} = \tan. (\theta - 45^\circ)$$

The auxiliary angle artifice is often handy. Here it enables us to obtain a direct solution of the three-point problem; and the same formula covers every case. Let M = 34°, N = 48°, ACB = 161°, AC = 5, BC = 7·4, to correspond with the figure in this Appendix, and the solution is indicated below, first finding the value of θ, and then $\frac{1}{2}(x - y)$. It will be noticed that $(x + y) = 360^\circ - (M + N + ABC) = 360^\circ - 243^\circ = 117^\circ$; and, therefore, $\frac{1}{2}(x + y) = 58^\circ\ 30'$. P is the sought ship's position.

7·4 log.	·86923
34° sin.	9·74756
48° cosec.	0·12893
	0·74572
5 log.	·69897
θ tan.	·04675
$\therefore \theta = 48^\circ\ 5'$	

$(\theta - 45^\circ)$ tan.	8·73132
$\frac{1}{2}(x + y)$ tan.	0·21268
$\frac{1}{2}(x - y)$ tan.	8·94400
$\therefore x - y =$	10°
$x + y =$	117°
$x =$	63° 30′
$y =$	53° 30′

See Appendix (E) on next page.

7917·58	3·8985925
3·1415926	0·4971499 +
Circumference in statute miles	4·3957424
5280 feet in one mile	3·7226339 +
Circumf. in feet = 131,333,746	8·1183763
Circumf. in minutes of arc = 21600′	4·3344538 −
Mean Nautical mile = 6080·265 feet	3·7839225

APPENDIX (E).

The mean radius of an oblate spheroid is the radius of a sphere of equal volume, and is equal to $\sqrt[3]{(a^2b)}$ where a is the equatorial and b the polar radius. The earth's mean radius is therefore 3958·79 statute miles, and according to this way of looking at it the mean sea mile would equal 6080·3 feet. In the United States the nautical mile is defined to be one-sixtieth part of the length of a degree of a great circle of a sphere the surface of which is equal in area to the area of the surface of the earth. This value, on Clarke's spheroid, is 1,853·248 metres.

APPENDIX (F).

As the magnetic poles are approached it may be assumed that, in conformity with the general law of magnetism, the deflections of the needle would become larger than here recorded; but this is a matter of more interest to the scientist than to the navigator.

APPENDIX (G).

The mariner's compass is found to be disturbed by submarine influences near North Quarken, Gulf of Bothnia; Oxelosund, Sweden; Cape St. Francis, Labrador; Cossack, N.W. Australia; New Ireland and Bougainville, Solomon Islands; Tumbora volcano, Sumbawa Island, near Java; St. Mary's Isle, near Madagascar; Delagoa Bay; Iceland and its adjacent waters; Odessa Bay, and the shoal south of it; and Isle de Los, W. coast of Africa.

APPENDIX (H).

In Walker's Taffrail log the bell sounds at every $\frac{1}{8}$th part of a knot run by the ship, therefore $\frac{600}{\text{seconds}}$ = knots. Thus, if the interval between two strokes of the bell be 40 seconds, the hourly speed of the ship is 15 knots. A small table like the subjoined may be stuck up in the chart-room :—

s.	knots.	s.	knots.	s.	knots.
50 =	12·0	46 =	13·0	42 =	14·3
49 =	12·2	45 =	13·3	41 =	14·6
48 =	12·5	44 =	13·6	40 =	15·0
47 =	12·7	43 =	14·0	39 =	15·4

The governor should always be used with a Taffrail log, otherwise it rotates by fits and starts, and the mechanism is more liable to suffer from the rapid spinning which occurs after the line gets sufficiently twisted to overcome the friction induced by the drag of the rotator.

In the case of Harpoon logs a guard of two pieces of crossed iron should be seized to the line about a couple of fathoms or so ahead of the log. Its business is to arrest seaweed, waste, and rubbish, which would otherwise foul the log and render it useless for the time being.

APPENDIX (I).

It may be taken as quite beyond the realms of controversy that the moon has absolutely no *direct* effect upon weather; and even an *indirect* effect, *in certain localities*, is doubtful. For example, in Torres Straits gales are remarkably prevalent about the times of Full and New Moon, or, in other words, at Springs. During 1841-44, Dr. Rattray, of H.M.'s surveying ship, *Fly*, noticed that at these periods there was a large area of coral reef uncovered at low water, extending out from land some 60 or 70 miles, and the great heating by the sun's rays of this large area has a tendency to cause gales at F. and C. Thus in this locality the moon, operating through the tides, *indirectly* produces (with the sun's assistance) a meteorological disturbance at regular periods, and of considerable magnitude. Proof, however, is wanting.

Again, where there is much rise of tide, say in the upper portion of the Bristol Channel, there must be some displacement of air by the incoming volume of water, quite apart from the effect produced by submergence of miles of heated tracts of land, and this is also alleged to have some effect.

Pilots of rivers and estuaries like the Mersey, the Dee, or the Clyde, are familiar with these local effects, such as a breeze springing up with the flood, &c., though they may not be able to define the true cause.

Again, in very many tropical ports—Bombay for example, during the N.E. monsoon—land and sea breezes alternate with wonderful regularity. Each forenoon, the heated land draws to it the sea-breeze (or "Doctor"), and right welcome it is. This dies away after nightfall, and vessels in the offing experience an offshore wind owing to the land having become cooler than the sea. Anyone who has beat up the Malabar or Coromandel Coast is familiar with these changes, which are all due to *fluctuations of temperature.*

One must learn to look beyond his nose for causes.

APPENDIX (J).

From Syzygy to Quadrature the tide *primes*, and for three days or so after Springs the interval between the corresponding tides of successive days is *less* than the average 50m.

Per contra, from Quadrature to Syzygy the tide *lags*, and accordingly, for about three days after Neaps the opposite effect is produced.

APPENDIX (K).

On the night of 31st October, 1876, a storm-wave 10 feet high swept over both banks of the Magna and the islands in its mouth; 98,000 people were drowned. "Soondrebun" of Bengal, sometimes written "Sundarband" or "Sunderbunds."

APPENDIX (L).

Another method of finding the Mean Time at ship and also at Greenwich of the meridian passage of a star, is as follows:—

Example.

What was the Mean Time at ship and at Greenwich of the meridian passage of * Procyon on February 19th, 1895, the Longitude being 45° W.?

	H.	M.	S.	
R.A. of Procyon (page 332, *N.A.*)	7	33	50	
	24			
	31	33	50	
Sidereal Time at Green. Mean Noon	21	56	44	
Approx. Mean Time of transit at ship	9	37	6	
Longitude in Time	3	0	0	W.
Approx. G.M. Time	12	37	6	

	H.	M.	S.	
Sidereal Time at G.M. Noon	21	56	44	
Acceleration for 12h. 37m. 6s.	+	2	4	
Corrected Sidereal Time	21	58	48	
	31	33	50	
Mean Time at ship at transit	9	35	2	
Longitude in Time	3	0	0	W.
Corrected Greenwich Mean Time	12	35	2	

If still greater accuracy be required, the foregoing must be repeated:—

	H.	M.	S.
Sid. Time at G.M. Noon (page 21, *N.A.*)	21	56	43·75
Acceleration for 12 hrs.	+	1	58·28
" " 35m.	+		5·75
" " 2s.	+		0·00
	21	58	47·78
	31	33	50·00
M.T.S. of transit of * Procyon on Febry. 19th	9	35	2·22

APPENDIX (M).

For pilotage purposes in confined water spaces, everyday experience teaches that the compass cannot claim to be more than an *auxiliary* to the eye methods commonly employed. Where changes in direction are many and rapid, time is wanting to lay off positions by the comparatively slow process of cross-bearings:—take the more intricate parts of the estuaries of the Thames and Mersey for example. It is due to this very obvious fact that a purely local pilot never consults a chart; either he is guided by the mostly-present buoys, or, in their absence, by transit-marks in the day-time, and by range lights, coloured sectors, and maskings at night.

Where banks are much given to shifting without permission, as in the Húgli, or, say in Yarmouth Roads, the buoyage has to be re-arranged at short intervals, and pilots have to look out for fresh transits. Now, as the charts of such unstable localities cannot be kept precisely up to date, the sensible navigator, on arriving within pilotage limits, hauls up his courses, backs the main-topsail, hoists the "Jack" at the fore, puts a Jacob's ladder over the lee side, and gets a boat-rope ready *well forward.* Then "local talent," when it comes on board, does the rest as above described.

But intricacy is a question of degree, and outside of Europe there are heaps of danger-strewn places with a paucity of buoys, lights, and pilots—perhaps none at all—where the navigation, though demanding much skill and clear-headed judgment, permits of more deliberation. The navigator thus left to his own devices has to fall back on the tools of his trade, and, unless familiar with the potentialities of Sextant and Station Pointer—the first as an angle-measurer, and the second as an angle-plotter—looks to his ancient friend "Cross-bearings" to get him along. Here, then, it is proper to remind him that if the ship has to pursue many and widely-varying courses, it is very important to have a *closely adjusted* navigating compass (*see* clause (4), page 642), as there is always danger at such times of applying the Deviation the wrong way; and though such Deviation may be small, its misapplication just doubles the effect on course or bearings. In the Royal Navy, during fleet movements, a "manœuvring compass" is kept in close adjustment for the reasons here given.

But there yet remains an equally important point which the man entrusted with the safety of a ship cannot afford to overlook: owing, in some cases, perhaps, to their more striking appearance, or some unaccountable whim of the moment, the navigator may be beguiled into selecting the more distant visible objects for cross-bearings, and this may easily prove fatal. *Provided they are well defined and correctly delineated, preference should always be given to objects near at hand.*

An error in bearing of a paltry quarter of a point—from whatever cause or unhappy combination of causes—is well within the bounds of probability. Now, with the object so near say as one mile, the ship's position due to such an error is only vitiated to the trifling extent of half a cable; but should the object happen to be five miles off, the displacement amounts to a quarter of a mile, and at ten miles to half a mile. At either end of the Magellan Strait tempting objects, ten-mile and upwards, are quite common, and an error in bearing of 3° or 4° would probably entail disaster.

It may be argued that the natural tendency is to take bearings of the nearer land-marks; perhaps so, but the writer has so often seen the contrary done without any apparent reason, that it is just as well to emphasize by repetition the last paragraph of page 104. See also page 149.

It is greatly in favour of the Station Pointer method of "fixing" that it is free from Deviation, and that a sextant-angle can be taken ever so much more accurately than a compass-bearing—especially should there happen to exist the not unusual accompaniments of sea and wind to make things lively. These undoubted advantages give correspondingly greater liberty in choice of objects.

It is regrettable that one or two shipmasters, *who have never tried it*, publicly jeer at the Station Pointer as newfangled, expensive (which it is not), unpractical, and requiring a mail steamer's complement of officers. This is because, unfortunately, they know no better, and are therefore altogether out of their proper sphere when they undertake the rôle of critics. Theirs is a prejudice which experience would dispel: such men, by way of mental reparation, often become extravagantly enthusiastic about that which they had previously condemned.

All the recognised instruments of navigation—and the Station Pointer is now one of them—have their legitimate times and uses, as, in previous pages, the writer has endeavoured to shew, and the navigator must learn to discriminate. Once more, "Knowledge is Power."

If the recommendation is to use near objects for "fixing" ship, the exact converse applies when adjusting compasses or ascertaining Deviation by known bearing of a terrestrial object. In these latter cases it is better that the object should be as far away as possible, compatible with distinct vision (see paragraph near bottom of page 618, *et sequitur*).

The two aspects of the bearing question dealt with in this Appendix are entirely distinct, and must not be confused with each other.

APPENDIX (N).

DEFINITIONS.

Here and there throughout the text various definitions in Nautical Astronomy have been introduced in a casual way as necessity has arisen; but now that the Board of Trade has stiffened its back, it appears desirable to recapitulate them systematically, and add such others as are wanting, so that the student may not be put to the inconvenience of referring to other books—perhaps not accessible at the moment—for enlightenment regarding the various technical expressions he may happen upon from time to time.

It may be argued with some show of truth that the proper place for these definitions is at the beginning of Part II., but on the whole they are somewhat dry reading, will be superfluous to some, and likely to "choke off" those who require a little coaxing. They are therefore relegated to an Appendix, where they will be handy when wanted.

Care has been taken to arrange the definitions in such a sequence that, as far as possible, each one is preliminary to the next. The simpler ones have also been put first. It follows that it will not do to skip, or to begin anywhere but at the beginning, since the definitions are more readily grasped in proportion to the reader's acquaintance with those which have preceded any particular one.

It would of course be possible to put much more tersely the matter contained in the following pages, but in that case it would not be so readily understood by the less advanced student. In fact the heading is hardly correct, for what follows must be considered more in the nature of detailed *Explanations* than curt *Definitions.*

It is a misfortune that in the average book on Nautical Astronomy many expressions are employed which mean exactly the same thing, but the reader is not told so. Unless this redundancy is pointed out, confusion is apt to arise in the student's mind. In view also of the fact that *the bulk* of seamen have but scant mathematical training, nothing but the homeliest language has been made use of: so now to business.

The innocent little word "Circle" is so often encountered in these *explanations of definitions*, that it will be better to tackle it at the very outset.

1. **A CIRCLE** is a plane figure bounded or surrounded by a continuous curved line called the **circumference**, of which every part is at the same distance from a point within named the *centre.* It will be noticed that, strictly speaking, the circle is not the circumference, but the surface which it encloses.

In the English system the circumference is divided into 360°, and these again in minutes (′) and seconds (″) of *Arc.* The circumference may also be divided into hours, minutes, and seconds of *Time.* As very familiar examples of these two divisions we have the compass-card and a clock-dial.

Lines drawn from the centre to any part of the circumference are termed *radii*, and are of equal length; the length of any one of these when multiplied by 2 is equal to the **diameter**; and the diameter multiplied by 3·1416 is very nearly equal to the length of the circumference.

Radius must not be confounded with **Radian,** which is something totally different (*see* footnote, page 217).

If a circle be divided into two equal parts termed **semi-circles**, each will contain 180° or 12 hrs.; the line of separation is the *diameter*. For example, in the Tables of Burdwood and Davis the azimuth is reckoned through 180° in the eastern and western semicircles. If a circle be divided into four equal parts termed **quadrants**, each will contain 90° or 6 hrs. For example, the compass-card is divided from 0° at North and South to 90° at East and West. A *Right-angle* contains 90°; an *Acute-angle*, less than 90°; an *Obtuse-angle*, more than 90°.

Any portion of the circumference is called an **arc**, and the straight line connecting the extremities of an arc is termed the **chord** of the arc. The parts of the circle separated by the chord are termed **segments**. A semi-circle is a segment.

The **Complement** of an angle is what the angle wants of 90° or 6 hrs.; therefore, if the given angle be 60° or 4 hrs., its complement is 30° or 2 hrs. The **Supplement** of an angle is what the angle wants of 180° or 12 hrs.; therefore, if the given angle be 105° or 7 hrs., its supplement is 75° or 5 hrs. These two words are often contracted to "co" and "su," and used as a prefix to some other word; thus we have sine and "co-sine," versed sine and "su-versed-sine"; therefore, the log sine of 60° is the same as the log cosine of 30°, as may be seen by inspection of any Table of Trigonometrical Ratios.

A vast deal more might be written about a Circle and its properties, which, however, would be out of place for the purpose in view. It is said that to describe a true circle is easier than to draw a perfectly straight line.

2. **A SPHERE** or **Globe** is a solid figure bounded by a curved surface, every point on which is at the same distance from an interior point called the *centre of the sphere. Every* plane section of a sphere is a circle. For example, imagine a billiard ball to be cut clean through in such a manner as to divide it very unequally, then the flat side or section of each of the two pieces, whether the large or the small, will be a true circle, provided the cut is a clean one. (The meaning of the word **plane** is given on page 337.) A "plane" has no material existence, it is devoid of thickness, it is merely what is termed an "abstract idea." In geometrical reasoning we have to suppose a good many impossibilities: for example, a "Line" is length without breadth; and a "Point" has no magnitude.

3. **A GREAT CIRCLE** is one which divides a sphere into two *equal* **parts**; and to do so its plane must pass through the dead-centre of that sphere; but it is free to do so in an infinite number of directions—there is no limit when we are dealing with imaginary planes. For example, an imaginary line joining *any* two stars in the firmament constitutes an arc of a Great Circle; it matters not whether the stars lie vertically, horizontally, or

obliquely to the observer. Pursuing this matter just a trifle further,—if we take haphazard any *three* stars not in a straight line, the three connecting lines would be arcs of Great Circles lying in different planes, but each passing through the centre of our globe, and the surface of the sphere included by the three arcs would be **a spherical triangle.** It is clear, therefore, that any number of such Great Circles may be considered to exist in space.

The **Poles** of a Great Circle are the extremities of that diameter of the sphere which is perpendicular to the plane of such Circle. For example, the **Equator** is a Great Circle, whose plane—passing through the centre of the Earth—divides it into the Northern and Southern Hemispheres, with their corresponding North and South Poles.

Now as all Great Circles truly *bisect* each other, it follows, let their inclination be what it may, that each one must intersect the Equator in two opposite points; and the two opposite points of *any* Great Circle must be 180° apart. (*See* definition No. 8.)

The Angle at the Pole of a Great Circle is measured by the arc of the Great Circle which subtends that angle. Think this over till thoroughly comprehended, and then don't forget it; as it is a rule requiring constant application. Still taking Mother Earth by way of illustration, the Angle at the Pole would be subtended by an arc of the Equator in the case of a difference of longitude, say, between the meridians of Washington and Greenwich. Or, supposing an observer to be *on* the Equator, in Long. 0°, **the Angle at the Zenith** would be subtended by an arc of the celestial meridian of 90° east and west longitude. In each of these two cases the Great Circles subtending the angles are perpendicular to each other; but, as already stated, Great Circles may intersect at *any* angle of inclination. Now if the first two lines of this paragraph are understood, it will be seen that *the Angle at the Poles of the* **Ecliptic** (*see* definition No. 10) would not be subtended by an arc of the Equinoctial, which intersects the Ecliptic, but by the Ecliptic itself. But we are getting a little too "previous."

The **Vertex** is the point of highest latitude touched by a Great Circle, not being the Equator; and there are of necessity two such vertices, just in the same way as there are two points of intersection. These Vertices are diametrically opposite to each other, both in latitude and longitude,—one in the Northern, and the other in the Southern Hemisphere: if so, they must be 180° apart, and 90° distant in each direction from the two points where the Great Circle to which they belong intersects the Equator. Therefore, if you know the longitude of these crossing places, you also know the longitude of each vertex, and *vice versâ.* So much for the longitude; but what about the latitude? Well, this is determined with equal readiness, since the angle of intersection is *always* equal to the **Latitude of Vertex.** This is not chance; it is a law of "spherics." There will be more said about this peculiarity of Great Circles when we come to the Ecliptic.

The meridian of longitude which passes through the Vertex is known as the **Meridian of Vertex,** and is the only one which cuts the Great Circle at right-angles. It is useful to remember this peculiarity also.

Great Circles and their Poles are scattered about everywhere and anywhere—millions of them. They are for ever cropping up in Nautical

Astronomy, and therefore in Navigation, which is based upon it. But if you know one, you know the whole family, and they behave exactly alike in similar circumstances.

4. **A SMALL CIRCLE** is an insignificant and distant connection of the Great Circle family. One does not hear so much about it in Nautical Astronomy. It is rigorously excluded—not, indeed, from the ordinary *family circle*—but from the *family triangle*, which is an exclusive meeting of three Great Circles—presumably members of the "upper circle." At such a meeting a Small Circle would be regarded as an interloper, and put out, being quite inadmissible in such high society.

A Small Circle divides a sphere *unequally*, and consequently its plane cannot pass through the centre.

5. **THE CELESTIAL SPHERE** may be conceived to be an immense spherical dome or shell, with the stars as glittering points on its *inner* surface, and ourselves as a speck at its centre. Upon this sphere we imagine certain lines to be traced (corresponding to similar imaginary lines on this Earth), whereby may be fixed the *apparent* positions of the heavenly bodies, and their motions ascertained and described. The *apparent* place of a heavenly body depends solely upon its *direction* from the observer, and has nothing whatever to do with its actual *distance*.

With the solitary exception of our troublesome neighbour the Moon, the **parallax** of all the other bodies with which seamen are concerned is so insignificant—owing to their vast distance—that in *practical* navigation it is usual to disregard it utterly. It would therefore be quite immaterial whether such bodies were observed from the centre or surface of the Earth: the measurements would be identical.

With our own satellite it is different: owing to the Moon's proximity, all lunar observations have to be reduced to the Earth's centre. The elements in the *Nautical Almanac* are—as may well be imagined—computed as between the centres of the various heavenly bodies. The Celestial Sphere is often spoken of as the "Celestial Concave," since it is the *inner* surface we are supposed to be looking at.

6. **THE POLES OF THE CELESTIAL SPHERE** are two fixed points in the heavens where, if a star were situated, it would suffer no displacement whatever during the 24 sidereal hours occupied by the *apparent* rotation of the sphere on its axis: consequently, as we shall see by-and-bye, such a star would have no "diurnal circle." **Polaris** being distant upwards of a degree from the Celestial Pole, does not quite fulfil these conditions, and only approximately represents the place of the Pole. It *has* a diurnal circle—though a very small one—which is gradually getting less, but will never reach the vanishing point.

The line joining these two fixed points is the **axis** of the celestial sphere about which it *seems* to rotate. To its inhabitants, the Earth appears to be at rest, and the celestial sphere to move round it from east to west. In reality it is just the other way about (*see* footnote, page 396). Do not get "mixed" over this capsizing of the arrangement of the universe.

The Axis of the Earth, *and all lines parallel to this Axis*, point to the Celestial Pole (*see* defin. No. 25). The North *Point* which is *on* the horizon, must not be confounded with the North *Pole*, which has an elevation *above* the horizon equal to the latitude of the observer.

7. **THE EQUINOCTIAL CIRCLE,** or **Celestial Equator,** is a Great Circle midway between the poles of the celestial sphere, and therefore 90° from each. It is in fact the Earth's equator extended to the heavens. When the Sun is crossing this circle in spring and autumn (declin. 0°), day and night are—Poles excepted—everywhere equal in duration (*see* page 398).

The Equinoctial Circle forms the horizon of an observer standing at either pole of the Earth, and as soon as the Sun appears above it, there will be constant daylight for a period of six months. This is to compensate him for the other six months of the year during which there would be modified darkness. (*See* para. 3, page 407).

In speaking of the Equinoctial Circle the second word is often dropped altogether. The *Equinoctial* is to the heavens what the Equator is to the Earth.

8. **THE VERNAL EQUINOX,** or **First Point of Aries,** is used by astronomers and navigators as a reference point in the sky, much the same as Greenwich is used as a reference point on the Earth (*see* page 398). The Equinoctial Point is the starting place for Right Ascension, Sidereal Time, and Celestial Longitude : for brevity sake it is cut down to "The Equinox."

The **Autumnal Equinox** is the opposite point, where the Ecliptic cuts the Equinoctial when the Sun is moving south. The Ecliptic and Equinoctial being great circles, the Vernal and Autumnal Equinoxes are of course 180° apart : to traverse this space it takes the Sun six months. Do not confuse "Equinox" with "Equinoctial": one is a Point, the other is a Great Circle.

9. **THE EQUINOCTIAL COLURE,** or **Zero Hour-Circle,** is a Great Circle passing through the celestial poles and the equinoctial points. That half which passes through the *vernal* equinox may be regarded as **The Celestial Prime Meridian.**

10. **THE ECLIPTIC** is that Great Circle in the heavens which the Sun *seems* to describe in the course of a year. It is better explained as the trace of the plane of the Earth's *orbit* upon the celestial sphere. It derives its name from the fact that eclipses can only occur when the Moon is crossing it.

As before stated, the Ecliptic cuts the Equinoctial at the vernal and autumnal equinoctial points. Midway between these come the vertices of the Ecliptic, known as the summer and winter **Solstices,** which mark the position of maximum declination (23° 27′ N. and S.). Here for a brief spell the Sun seems to stand still before retracing his steps to the other hemisphere.

The great circle passing through the solstitial points, the poles of the equinoctial *and* ecliptic is termed **The Solstitial Colure.** It lies at right-angles to the **Equinoctial Colure** (*see* No. 9). The Solstitial Colure is the "Meridian of Vertex" of the Ecliptic.

The terms "summer and winter solstices" are, of course, only relative, since the English summer is the Australasian winter, and *vice versâ*.

By "equinoctial point," or "equinox," is usually meant the *vernal* equinox, or 1st Point of Aries. The other is much less heard of.

11. **OBLIQUITY OF THE ECLIPTIC** is the practically constant angle (23° 27′) which the ecliptic makes with the equinoctial at their points of intersection. In accordance with the laws of "spherics," this angle is equal to the polar limit of the Sun's declination.

The Poles of the Earth, instead of being perpendicular to the plane of its orbit round the Sun, are inclined to it at the above angle. It is this beneficent arrangement which gives us the four seasons of the year, and the varying length of day and night.

12. **THE TROPICS** are two small circles—parallel to the equinoctial—drawn through the solstitial points. The Sun never gets beyond these boundaries. The northern is the **Tropic of Cancer,** and the southern the **Tropic of Capricorn.**

13. **THE TORRID ZONE** is the space on the surface of the Earth lying within the tropics. Twice in the year at noon the Sun is over-head to every place within this area, and never to any place outside of it. It is mostly a hot shop.

14. **THE POLAR CIRCLES** are small circles distant 23° 27′ from either pole. The northern is called the **Arctic Circle,** and the southern the **Antarctic Circle.** Their latitude, therefore, is 66° 33′ N. and S. respectively.

15. **THE FRIGID ZONES** are the spaces lying within the polar circles. If the torrid zone—temperature apart—has its little peculiarity, so have the Frigid Zones, but in a more marked degree; for at places within their inhospitable limits the Sun keeps above the horizon during part of the summer, and below it during part of the winter. The extent to which this happens depends upon the sun's declination and the distance of the place from the pole.

16. **THE TEMPERATE ZONES** are the spaces lying between the tropics and polar circles. They have nothing to do with the great Temperance Question or the principles of the natives.

17. **LATITUDE.** The Celestial Latitude of a body is reckoned *from* the ecliptic toward one or other of its poles, and is measured on a "circle of latitude" passing through the body. A circle of celestial latitude is a great circle perpendicular to the plane of the ecliptic. Terrestrial Latitude of a place is reckoned *from the equator* towards one or other of the poles of the Earth, and is measured on a meridian.

18. **LONGITUDE.** The Celestial Longitude of a body is measured *on* the Ecliptic, starting from the equinoctial point. It is always reckoned in arc, and from west to east throughout the complete 360°. Terrestrial Longitude of a place is measured *on the Equator*, starting in both directions from the meridian of Greenwich, and is reckoned up to 180° E. and 180° W.

The latitude and longitude of the Sun and Moon are given in the *Nautical Almanac*, on pages III. and IV. for the month. They are not used by navigators.

19. **THE ZENITH,** in general terms, is the point *vertically over-head* in the celestial concave: for example, it is the point whence a plumb-line would meet the surface of the Earth. The direction of the plumb-line is determined by the direction of *gravity* at the place of contact: this is very seldom indeed exactly towards the centre of the Earth (*see* pages 9 and 10).

Were the Earth a true sphere, the Zenith might be defined as the point where a line drawn from the centre of the Earth, upwards through the observer, would meet the sky. But since the Earth is *not* a true sphere, this second definition really indicates a point known as the **Geocentric Zenith**. Moreover, the **True Zenith** is only correctly determined when the direction of gravity is not interfered with by *local* and abnormal influences (*see* par. 3 of page 10).

20. **THE ZENITH DISTANCE** at any moment is simply the angular distance of a body from the observer's Zenith, or what the true altitude wants of 90°. The Zenith Distance is therefore the *complement* of the altitude. The body may have any bearing. When a body is on the horizon its Z. D. is 90°. It is measured on a vertical circle, or circle of altitude.

21. **MERIDIAN ZENITH DISTANCE** only differs from No. 20 in being the body's distance from the zenith *at the instant of passing the observer's meridian;* in the case of the Sun this would be at apparent noon, and at such times the bearing would be either North or South.

22. **THE NADIR** is the point under foot which is opposite to the zenith. In observatory work it is readily determined by directing the telescope downwards to a basin of mercury between the piers of the instrument, and slowly moving it by the proper screw until the image of the horizontal wire in the reticule, as seen by reflection, coincides with the wire itself. (*See* page 80). The "horizontal point" for the zero of the instrument is of course 90° from the Nadir.

This method has superseded the old-fashioned ones, which, besides being much more troublesome, were afflicted with the uncertainties of that bugbear of the astronomer—refraction. The Nadir is seldom or never referred to in navigation.

23. **HORIZON** (*see* Plate) is a general term which, where navigation is concerned, resolves itself into the *Rational*, the *Sensible*, and *Visible* horizons. But in the end they all come to the same thing.

24. **THE RATIONAL HORIZON** is a great circle of the celestial sphere, having the zenith and nadir for its poles; it is therefore half-way between them, and 90° from each. The plane of the Rational Horizon passes through the centre of the Earth. Wherever he may elect to go, each individual carries with him his own Rational Horizon, so that their number is infinite: but however many there may be, or however varied their angles of inclination, they one and all have the same centre (*see* page 322). The observer's Horizon has several faithful companions which never desert it. They are—the Zenith, Meridian, Prime Vertical, and a host of other Vertical Circles. (*See* No. 27).

25. **THE SENSIBLE HORIZON** is a small circle parallel to the particular rational horizon to which it corresponds, and its plane passes through the eye of the observer.

Though separated by the semidiameter of the Earth (nearly 4,000 miles), it is evident that when extended to this infinitely distant surface of the celestial concave—as in the case of the fixed stars—the two horizons resolve themselves at the "vanishing point" into a single great circle (*see* pages 320-323). They may therefore be treated as one and indivisible, except when the Moon is concerned.

26. **THE VISIBLE, or Apparent Horizon,** is the line where the sea and sky appear to meet. It is a small circle parallel to the others, but depressed below the sensible horizon by an angular amount depending upon the height of the eye above the surface of the sea: this angular amount is familiar to seamen as the "dip of the horizon." There is **True Dip** and **Apparent Dip**: in the latter the effect of refraction is allowed for. The exact formula for true dip is :—

$$\text{Sin.}\tfrac{1}{2}\Delta = \sqrt{\frac{h}{2(R+h)}}$$

where R = mean radius of the Earth, Δ = true dip, h = height of eye. With R = 20,902,412 feet, and h = 40 feet, the true dip is 6′ 43″·5.

27. **VERTICAL CIRCLES, or Circles of Altitude,** are great circles passing through the zenith and nadir, and therefore perpendicular to the observer's horizon in every direction.

28. **A CELESTIAL MERIDIAN** is a great circle passing through the poles of the heavens, the zenith and nadir: it therefore marks the north and south points of the horizon, and lies at right angles to the equinoctial and horizon. It is a particular case of a vertical circle. The Celestial Meridian is merely the plane of a terrestrial meridian extended to the celestial concave. Though very important in its way, it is only a *local* reference line. There are of course any number of meridians.

Please understand that, unless otherwise specified, the word "meridian" as used in these explanations is to be considered the meridian of the *observer.*

29. **THE PRIME VERTICAL** is the vertical circle passing through the zenith at right angles to the meridian: it therefore runs east and west, and cuts the horizon at those points. It is essentially a Great Circle. All bearings mentioned in these "explanations" are *True* bearings.

30. **HOUR-CIRCLES** are great circles of the celestial sphere *passing through its poles,* and therefore at right angles to the equinoctial: they correspond exactly to the meridians of the Earth, and are sometimes termed "Circles of declination."

31. **THE ALTITUDE** of a heavenly body in general terms is its angular elevation above the horizon, and is measured by the arc of a vertical circle. In practice there are three kinds of Altitudes :—(1) The *Observed* Altitude

as taken with a sextant; (2) The *Apparent* Altitude, which is got by applying to the observed altitude the instrumental errors and dip, also semidiameter—if any. It is therefore the angle of elevation of the line *drawn from the observer* to the *apparent* place of the body; (3) The *True* Altitude is got from the apparent altitude by the application of refraction and parallax. The latter—in the case of stars—is non-existent, and in the case of the Sun and planets may be neglected with safety. With the Moon it is a big item.

The True Altitude, therefore, is the angle of elevation of the line *drawn from the centre of the Earth* to the *True* place of the body.

In the case of the troublesome Moon the altitude needs yet another minor correction. The nearer a body is, the larger it looks: now, when the Moon is right over-head, it is nearer to the observer by half the Earth's diameter than when it is on his horizon; hence its angular diameter when in the zenith is appreciably larger, and the increase is called **Augmentation.**

The Moon's semidiameter, as recorded in the *Nautical Almanac*, is the angle under which it would appear if viewed from the centre of the Earth. But we don't view it from the centre of the Earth, and so the semidiameter needs a *plus* correction depending for amount upon the Moon's Altitude. This is given in tabular form in all epitomes, but it is so small as not to be worth bothering about except in the case of a Lunar Distance, if ever used at sea, where "Every mickle mak's a muckle." (For refraction *see* page 91, and for parallax *see* pages 320–323.)

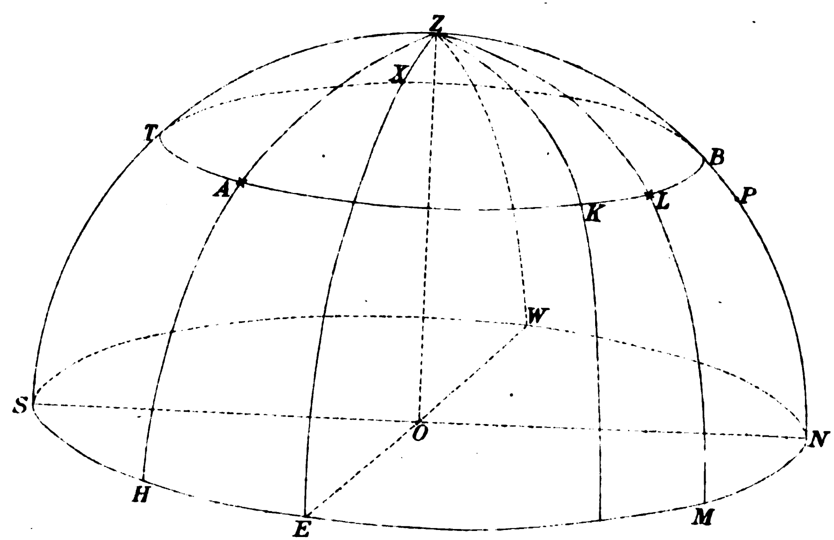
32. **PARALLELS OF ALTITUDE** are small circles parallel to the horizon. They are more commonly called "Circles of Equal Altitude." (*See* page 489.)

33. **THE DECLINATION** of a body is its angular distance north or south of the equinoctial, and is measured by the arc of the hour-circle passing through the body. Declination ranks in the heavens with Latitude on Earth: thus a star whose declination is, say 40° N., will pass the meridian in the zenith of all places in Latitude 40° N.

34. **POLAR DISTANCE** is the body's angular distance from the *elevated* pole. When the body is on the celestial equator (declination 0°) its Polar Distance is 90°.

When the declination and the observer's latitude bear the same name, the Polar Distance is the *complement* of the declination; but when they are of contrary names the Polar Distance is the *sum* of the declination and 90°. Thus if the observer be in north latitude, and the declination be 20° N., the Polar Distance would be 70°; but if the declination were 20° S., the Polar Distance would be 110°.

35. **THE AZIMUTH**, or **True Bearing**, is the angle *at the zenith* between the observer's meridian and the vertical circle passing through the body. It is measured by *the arc of the horizon* intercepted between the *north* or *south* point and the foot of this vertical. In all cases a body will change its Azimuth most rapidly when on the meridian, and least rapidly when on the prime vertical. If for some special purpose the Azimuth should require to be



THE HORIZON AND VERTICAL CIRCLES.

(*Vide* pages 836—837.)

S H E N W = The Horizon.
O = The Observer.
O Z = A plumb-line from
Z = The Zenith.
P = The Pole.
S T Z P N = The Meridian.
N, S, E, W = The Cardinal Points.
E Z W = The Prime Vertical.

A = Altair.
T A K B X = Circle of Equal Altitude.
Z A H = Arc of the Vertical Circle of Altair.
H A = Star's Altitude.
A Z = Star's Zenith Distance.
Angle T Z A = Star's Azimuth, subtended by arc S H.
Angle E Z A = Star's Amplitude, subtended by arc E H.
Z L M = Arc of Vertical Circle passing through Star L.
All Vertical Circles are Great Circles.

TO FACE PAGE 739

known *very accurately* when the body is near the meridian, Time-Azimuths will give the best results: similarly, should the body be near the prime vertical, Alt.-Azimuths will give the best results.

The most favourable time for swinging ship for compass work is of course when the Azimuth is changing least rapidly, and this can be ascertained at a glance from Burdwood or Davis, according to the latitude and declination. The altitude, though, should never *exceed* 40°, and 30° is the ordinary limit. For ship work Time-Azimuths are more convenient than Alt.-Azimuths (*see* bottom of page 123).

But although they should be looked for, one cannot always *command* the most favourable conditions; when, unfortunately, they are absent, the philosophic sailor will comfort himself with proverbs suitable to the occasion, such as "Beggars cannot be choosers," "Half a loaf is better than no bread." Endeavour so to discipline your mind as always to be thankful even for *small* mercies. Contentment is happiness, though proper ambition is commendable.

36. THE AMPLITUDE is merely the complement of the azimuth of a body on the horizon, and is reckoned *from* east or west *towards* north or south. Thus, if the azimuth were N. 80° W., the corresponding Amplitude would be W. 10° N. In Burdwood and Davis the azimuth is counted through 180°, and one might wonder how the "complement" rule would then work. There is no difficulty. Imagine the amizmuth to be N. 120° W.; subtract from 180° and we get S. 60° W. for the azimuth. Now the complement of this is W. 30° S. = the Amplitude.

The Amplitude is defined as the angle between the prime vertical and that vertical circle which passes through the body when the latter is on the horizon.

Strictly, the term is only applied to a body at its rising or setting. It is dropping out of fashion, as no one now-a-days would dream of waiting for that which after all—when the critical moment arrived—might not be visible: we have all heard of such things as a "high dawn," "the Sun setting in a bank," &c.

Azimuth Tables and good bearing instruments make it easy to get compass observations almost at any hour.

In the days of *wooden* sailing ships it was not uncommon in the first or second dog-watch to see "the old man" solemnly laying his hand "on edge" (or the Gunter scale) over the compass, and squinting along it in the direction of the *setting* Sun. It was *so* easy to do, and the table in the Epitome obligingly gave the Amplitude without any calculation whatever. The *rising* Sun did not receive so much notice: the mate would be busy washing decks, and "the old man" had not yet turned out. Steel has changed all that, and compasses *insist* upon their claims to *constant* attention.

To an observer on the equator the Amplitude of a body is equal to its declination; thus, if the declination is 15° N. the body will rise bearing E. 15° N., and set bearing W. 15° N. Under all circumstances, however, *it bears the same name* as the declination.

When its declination is 0°, the body rises and sets due east and west *in all latitudes.* In high latitudes, when the body—instead of rising or setting vertically—skims the horizon obliquely, the visible Amplitude is only approximate, and a correction is necessary. Why should this be?

37. **TIME** is an all-important factor in our daily lives. "Punctuality is the soul of business," and though we have clocks and watches to keep us straight, there must be something to keep *them* straight in the first instance. This "something" is the uniform rotation of the Earth on its axis, which is always performed in exactly the same time, and thereby gives to us the portion of time known as a **Day**.

But there are "days" and "days." Broadly, a day is the interval between the departure of the observer's meridian from a heavenly body—not necessarily the Sun—and its next return thereto. It derives its prefix or christian name from the body with which the motion of the meridian is associated. If the various heavenly bodies preserved the same positions with respect to each other, the intervals between the departure and return of a meridian to each would be the same, and consequently days of all denominations—whether solar, lunar, or sidereal—would be of equal length. But this is not the case. The Sun (or more strictly, the Earth in its orbit), the Moon, and the Planets are in continual motion, with velocities not only differing from each other, but varying in each particular body; hence a big celestial complication, which cuts out plenty of work for the astronomer in the compilation of that "wonderful book of prophecy" the *Nautical Almanac*.

But our resources don't end here, for, ever so far away, beyond Sun, Moon, and Planets, there dwells the glittering host of stars—suns in various stages of existence. They possess, it is true, what astronomers call "proper motions" of their own; some speeding one way and some another, with velocities scarcely possible to realize; but owing to the *immensity* of distance which separates them from this Earth, their movements *inter se* are only barely perceptible in the observatory after the lapse of many years. So far, therefore, as we mortals are concerned, the stars are fixed points in the fathomless depths of the sky: the "Plough" of to-day is pretty much the "Plough" of a hundred years ago; so also with the other constellations,—within the memory of man they alter not.

This majestic phalanx sweeps round about the Earth unceasingly, keeping step exactly, and without any derangement of its formation. We turn to practical account the unfailing punctuality of this stellar procession by taking it as that particular measure of Time known as the **Sidereal day** of 24 Sidereal hours.

38. **A SIDEREAL DAY**, therefore, is the interval between the departure of a meridian from a given star and its return to the same, or the time occupied by the Earth in rotating once on its axis. This measure of time, ever available, is of invariable length.

To keep the ropes clear for running, we will at once draw a distinction between **rotation** and **revolution**. They should not be used indiscriminately. In these pages the first will always be understood to mean *a body spinning on its own axis*, like a teetotum, a top, or a merry-go-round; and the second, *the path or orbit of a body round its primary*. Thus the Earth *rotates* on its axis once in the course of a *day*, and *revolves* round the Sun once in the course of a *year*. The Moon revolves round the Earth, but its rotation is so very slow as to be only once in a revolution. The Moon, therefore, always shews us the same side. What the other side is like we don't know, though *Libration* enables us to peep round the corners to a small extent.

Also, in considering the various daily measures of time, the observer must stick to his post. If he deserts it for another, as a ship does on the ocean, the intervals between successive meridian passages will be longer or shorter according to whether he has moved westward or eastward. As we cannot venture just now to complicate matters after this fashion, the observer will please to consider his eye glued to the transit instrument of any one observatory he may select, Greenwich for choice.

39. AN APPARENT SOLAR DAY is the interval between the departure of a meridian from the Sun's centre and its return to the same. But from two causes this interval is a variable one, and therefore unsuited to the affairs of high-pressure civilized life; nor could clocks be constructed to keep pace with its vagaries.

Cause No. 1 is the apparent variable motion of the Sun in the ecliptic, due to the fact that the velocity of the Earth in its orbit varies with its distance from the Sun; and here, be it said, the Sun is nearest to us in the northern winter and furthest in the northern summer. The Earth's orbit, then, is not a true circle, but an ellipse, with the Sun in one of the foci.

Cause No. 2 arises from the Sun's apparent path not being coincident with the equinoctial, but inclined at an angle already explained as the "obliquity of the ecliptic." To know when the effect from this cause is least and greatest requires a little meditation. Just think it over.

A sun-dial shows Apparent Solar Time, and we also use this latter time at sea, where it is the custom to "make 8 bells" when the Sun is on the meridian at noon.

40. A MEAN SOLAR DAY. With a view to obtaining a *convenient* and *uniform* measure of time, astronomers have recourse to a Mean Solar Day, the length of which is equal to the mean or average of all the Apparent Solar Days in the year. An imaginary sun called the *mean* sun is made to take the place of the real Sun, and the interval between the departure of any meridian from the *mean* sun and its next return to it constitutes the Mean Solar Day. Being a uniform measure of time, we are enabled to make clocks and watches which will practically conform to it.

If the imaginary or mean sun could be observed on the meridian at the instant when the mean-time clock indicated 0h. 0m. 0s., it would again be observed there when the hands returned to the same position.

As the time deduced from observation of the *real* Sun is called *Apparent* time, so the time deduced from the *imaginary* sun is called *Mean* time.

Mean Time cannot be obtained from observation, because there is nothing to observe; but it may readily be deduced from an observation of the real Sun with the aid of the **Equation of Time** presently to be explained.

41. THE CIVIL DAY and **ASTRONOMICAL DAY.** The first named, or common mode of reckoning, consists of 24 mean solar hours, counted in two batches of 12 hours each. We have seen that the Solar Day really *begins* with the transit of one or other of the two suns across the meridian at mean or apparent noon, and this is the natural order of things if we accept the Sun as our time-keeper. But the Civil Day begins at the *preceding midnight*, and its first batch of 12 hours takes us to noon ; we then make a fresh start, and the second batch of 12 hours carries us on to the following midnight, and so completes the Civil Day. Hence the ordinary clock is only marked to 12 hours. At Bern in Switzerland there is a large public clock with its dial marked in two batches of 12 hours each, one lot for A.M. and the other for P.M.

The Civil reckoning is, therefore, always 12 hours in advance of the Astronomical reckoning; hence the well-known rule for determining the latter from the former, viz:—In civil time, with P.M. make no change ; but with A.M., diminish the day of the month by one, and add 12 to the hours. Thus:—January 2nd, 7^h 49^m P.M. civil time, is January 2nd, 7^h 49^m astronomical time ; but January 2nd, 7^h 49^m A.M. civil time, is January 1st, 19^h 49^m astronomical time. It will be noticed that Astronomical Time has no A.M. or P.M. but runs right through the 24 hours. This is the case with Sidereal Time also.

Ships' log-books used to be kept in astronomical time by some, since it seemed convenient. Other navigators preferred the log-book kept in what was called nautical time, which, like astronomical, commenced at noon. Hence the remark which used to be found in the last page of the harbour log:—"This day contains twelve hours to commence the sea log." Fortunately, for all concerned, Civil Time is now universal. The Nautical Day commenced 12 hours before, and the Astronomical Day 12 hours after, the Civil Day.

There being no room in the cramped columns of Railway time-tables to insert A.M. and P.M. except at the top, every traveller, other than a "bagman" used to find difficulty in sorting out times of arrival and departure over long routes, especially as 0^h 6^m P.M. was represented by 12^h 6^m P.M., which could only mean 6^m after *midnight*. At length a genius came along and hit upon the simple device of putting the A.M. figures in one kind of type, and the P.M. in another. Once more Columbus and the egg.

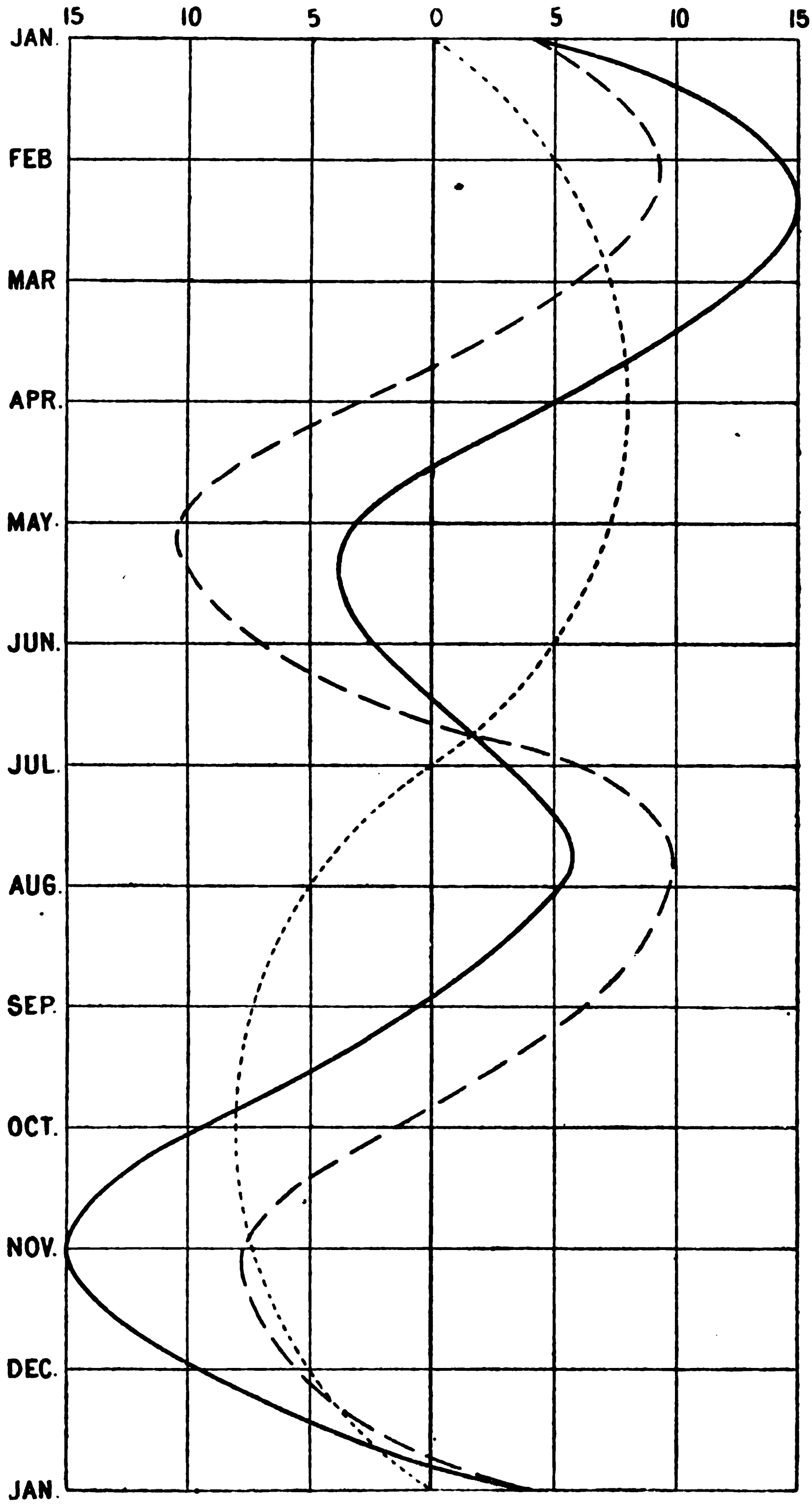
To summarise, the Civil Day begins at midnight and ends at the next midnight, which is the most convenient arrangement for the ordinary affairs of life on shore. The Astronomical Day begins at the noon between the two midnights, and ends at the next noon. It has been proposed to make the Astronomical Day conform to the Civil Day, but it entails such a general upset—including the *Nautical Almanac*—that whilst admitting its advantages, astronomers seem loath to make the change.

42. THE EQUATION OF TIME. The difference between the time given by the imaginary sun and the real Sun at any instant, is so termed. It is the angle *at the pole of the Equinoctial* included between the meridians passing through the centre of the real and imaginary suns respectively—that is to say, the difference between their Right Ascensions.

Sometimes the real Sun is ahead of the imaginary one, and sometimes astern of it, and this regulates the application of the Equation of Time as given in the *Nautical Almanac*, where it is additive and subtractive by turns.

From December 23rd to April 15th the real Sun is leading ; therefore, during this period the clock will be before the Sun.

From April 15th to June 14th the real Sun is astern of the other, and the clock will be behind the Sun.



EQUATION OF TIME.

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There being no room in the cramped columns of Railway time-tables to insert A.M. and P.M. except at the top, every traveller, other than a "bagman" used to find difficulty in sorting out times of arrival and departure over long routes, especially as 0^h 6^m P.M. was represented by 12^h 6^m P.M., which could only mean 6^m after *midnight*. At length a genius came along and hit upon the simple device of putting the A.M. figures in one kind of type, and the P.M. in another. Once more Columbus and the egg.

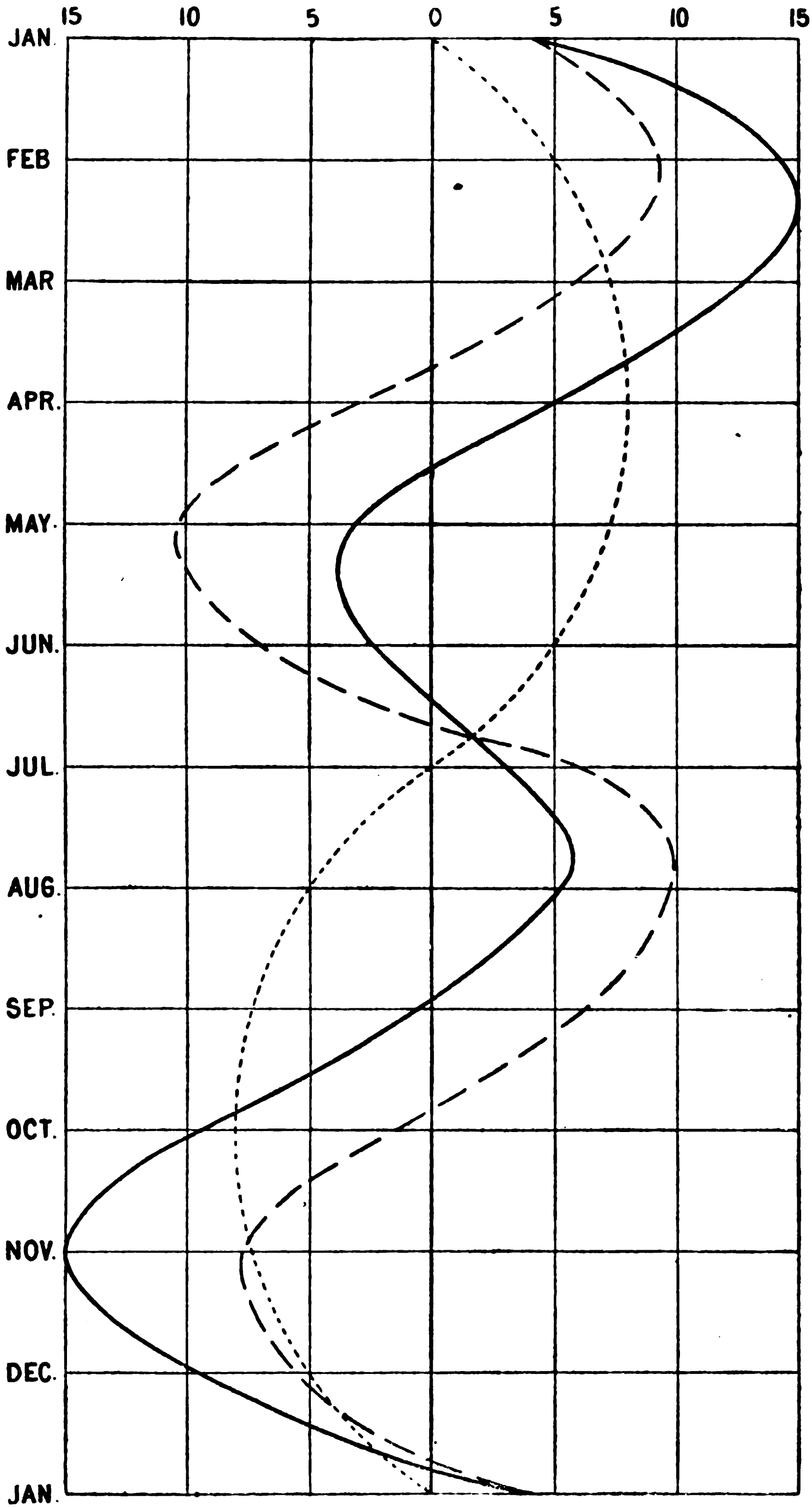
To summarise, the Civil Day begins at midnight and ends at the next midnight, which is the most convenient arrangement for the ordinary affairs of life on shore. The Astronomical Day begins at the noon between the two midnights, and ends at the next noon. It has been proposed to make the Astronomical Day conform to the Civil Day, but it entails such a general upset—including the *Nautical Almanac*—that whilst admitting its advantages, astronomers seem loath to make the change.

42. THE EQUATION OF TIME. The difference between the time given by the imaginary sun and the real Sun at any instant, is so termed. It is the angle *at the pole of the Equinoctial* included between the meridians passing through the centre of the real and imaginary suns respectively—that is to say, the difference between their Right Ascensions.

Sometimes the real Sun is ahead of the imaginary one, and sometimes astern of it, and this regulates the application of the Equation of Time as given in the *Nautical Almanac*, where it is additive and subtractive by turns.

From December 23rd to April 15th the real Sun is leading; therefore, during this period the clock will be before the Sun.

From April 15th to June 14th the real Sun is astern of the other, and the clock will be behind the Sun.



EQUATION OF TIME.

3 B

In the Figure the dotted curve gives the difference between the apparent Sun and the mean Sun for each month due to the orbit of the former being an ellipse. The curve shows the difference due to the angle between the ecliptic and the equator. The continuous curve is the combination of those two, and is the equation of time as given in the *Nautical Almanac.*

From June 14th to August 31st the real Sun has again got in advance, and the clock will be before the Sun. Finally, from August 31st to December 23rd the real Sun is behind, and the clock will be behind the Sun. The greatest value of the Equation of Time is $16^m\ 20^s$.

Now this matter of the clock being before or behind the Sun, as given in Whitaker's and other shilling almanacs, is apt to be confusing; but reference to our bosom friend the *Nautical Almanac* makes it plain enough. For example:—At 2 P.M. by the clock on May 1st, 1902, at Greenwich, required to know whether the clock is before or behind the Sun. (Remember that the clock shews Mean Time, while the Sun shews Apparent Time.)

On page 75 of the *Nautical Almanac* (page II. for the month) the precept enjoins that the Equation of Time shall be added to Mean Time to find Apparent Time.

	h.	m.	s.	
Clock =	2	0	0	or Greenwich Mean Time.
Equation of Time +		2	54	
Real Sun ...	2	2	54	or Greenwich Apparent Time.

Therefore the clock is behind the Sun.

43. THE LUNAR DAY. As with other heavenly bodies, this is the interval of time between the departure of any meridian from the Moon, and its next return thereto. So far this has been the wording used, and is the truer way of putting it; but generally the Earth is *considered* as standing still, and the other bodies revolving round it. If we adopt the same view, the wording must be altered to read like this:—A Lunar Day is the interval of time between two successive transits of the Moon over the same meridian. The meaning is of course identical.

On the average the Moon gains $12°\ 11'{\cdot}4$ on the Sun daily, so that she comes to the meridian $50{\cdot}5^m$ of solar time later each day. To find the mean interval between successive transits of the Moon we may use the proportion $(360° - 12°\ 11'{\cdot}4) : 360° :: 24^h : x$; whence $x = 24^h\ 50{\cdot}5^m$.

The variations of the Moon's motion in Right Ascension, which are very considerable, cause this interval to vary from $24^h\ 38^m$ to $25^h\ 6^m$.

44. SIDEREAL TIME at any place, at any moment, is the *western* hour-angle of the vernal equinox. When the equinoctial point is on the meridian of the observer, local Sidereal Time begins. At that instant, and at that particular spot, it is, so to say, **Sidereal Noon,** and a well-regulated sidereal clock should indicate $0^h\ 0^m\ 0^s$, quite irrespective of the time shewn by a mean solar clock, which might possibly indicate midnight, or any other hour.

All observatories are equipped with a sidereal clock, the face of which is marked up to 24 hours, and in this way it agrees with Right Ascension, which also runs continuously through 24 hours.

By a glance at his sidereal clock, and at the Right Ascension column in his star catalogue, the astronomer can tell in a moment what particular star is then nearing his meridian, and can set his transit instrument to the proper altitude for observing its passage. Let us imagine a case:—

On June 10th, 1902, the Astronomer-Royal at Greenwich, in Lat. 51° 28½′ N., finds the time by his sidereal clock to be 14 hrs., and wishes to test its correctness. From long practice he remembers that *Arcturus* has a R.A. of about this amount, and turning it up, finds it to be $14^h\ 11^m\ 13{\cdot}99^s$, therefore it will pass the meridian at that instant of sidereal time: this gives him 11^m in which to get ready. The declination of *Arcturus* is 19° 41½′ N., and its meridian altitude is found as follows :—

	°	′	
Latitude	51	28½	N.
Declination	19	41½	N.
Zenith Distance	31	47	N.
	90		
True Altitude	58	13	S.
Refraction	+	½	
Apparent Alt.	58	13½	S.

The transit is accordingly rotated on its supports to point to the southern heavens, and set to 58° 13½′. By this time *Arcturus* will be about entering the field of the telescope, so the astronomer will record the *minute* shewn by the clock, and pick up the beat of the pendulum, which in the stillness of an observatory is almost painfully distinct. Then, at the precise instant, when *Arcturus* is on the vertical wire representing the meridian of Greenwich, the second and tenth of a second will be noted by ear. Any disagreement between the observed time of transit and the star's R.A. is the error of the clock on *sidereal* time.

This illustrates the *principle* of the thing, but in practice many important niceties require attention to ensure accuracy, and the chronograph may be substituted for the ear.

Certain stars, whose places have been determined with the most pains-taking precision, are selected for this special purpose and get the name of "clock stars." The transit is supposed to point true north or south, but it might be a trifle out of the plane of the meridian, so the nearer the "clock star" is to the zenith the less will any error in azimuth be felt. Let the reader think this out and discover the reason.

To the navigator who is not furnished with a sidereal clock, and is constantly shifting his position, a most useful item in the *Nautical Almanac* is the **Sidereal Time at Greenwich Mean Noon.** With this and his chronometers he can get the sidereal time for any hour at Greenwich, or at ship, whenever the necessity arises (*see* pages 401-402).

Sidereal Time, then, is nothing more than the distance, at any moment, of the equinoctial point from the meridian of the observer, in whatsoever part of the world he may happen to be. (*See* footnote, page 330).

A sidereal day consists of $23^h\ 56^m\ 4{\cdot}09^s$ of mean solar time, and during it a meridian rotates through 360°. A sidereal day is therefore shorter than a mean solar day by $3^m\ 55{\cdot}91^s$ of mean solar time, and the deficiency is termed the Retardation of mean solar on sidereal time. This brings us to the fact that in the course of a year the Earth rotates on its axis 366¼ times; or we have that number of *sidereal days* as compared with 365¼ *solar days.* Leap year has been devised to dispose of the odd quarters, which, if neglected, would in process of time seriously derange the calendar. The "odd quarters" are not quite quarters, so a further correction has to be made at long intervals.

In the *Nautical Almanac*, on page III. of any month, in the centre column, will be found the **Mean Time of Transit of the First Point of Aries.** This is the distance (or hour-angle) of the *mean Sun* from the meridian at the instant when the *true* point of intersection of the ecliptic and equinoctial (called the First Point of Aries, or vernal equinox) is on the meridian of Greenwich. It is the time by a Greenwich *mean time* clock at the moment that a Greenwich *sidereal* clock indicates exactly $0^h\ 0^m\ 0^s$, and may be termed **Mean Time at Sidereal noon,** precisely as in the right-hand column of page II. we have **Sidereal Time at Mean noon.** It is useful for changing Sidereal Time into Mean Time.

Should the place of observation not be on the meridian of Greenwich, the mean time must be corrected by the *subtraction* of $9{\cdot}83^s$ for each hour (and in proportion for each part of an hour) of longitude if the place be to the *West* of Greenwich, but by its *addition* if to the East.

45. RIGHT ASCENSION is the angle *at the celestial pole* between the body's hour-circle and another which passes through the equinoctial point; the last of these two circles is distinguished as the **Equinoctial Colure, or Zero Hour-circle** (*see* definition No. 9). The Equinoctial Colure being a great circle, of course passes through *both* the equinoctial points—Aries and Libra. (*See* bottom para. of page 398).

R.A. is in the sky what Longitude is on Earth, though their starting points are not the same.

Right Ascension of a given body is virtually the Sidereal Time when such given body passes the observer's meridian. It is measured *eastward* by the arc of the equinoctial intercepted between the equinoctial point and the foot of the body's hour-circle.

The Right Ascension of Sun, Moon, Planets, and Stars, are *all* reckoned from the *same* point. The only difference is that stellar Right Ascensions are practically constant, whilst those of the other bodies require correction for Greenwich Date, more especially that of the rapidly-moving Moon.

46. RIGHT ASCENSION OF THE MERIDIAN sounds large, but is merely the observer's own R.A. *at any moment*, as would be indicated by his sidereal clock—if he had one, and therefore entitled to be called **Sidereal Time at Place.** Should the observer be afloat it would be equally proper to define it as the **Sidereal Time at Ship.** The example on page 402 shews how to find it at sea.

It is now advisable to call attention to the big distinction existing between the Right Ascension of a Star and the Right Ascension of the Meridian. The first named does not vary, because the star being a fixture in the celestial concave, the *interval* between it and the equally fixed "equinoctial point" remains practically constant, as may be seen by inspecting the Star List in the *Nautical Almanac:* the equinoctial point and the star *rotate in* *unison.* It is different with the observer; he being on Earth, and the equinoctial point being in the sky, they are all the time rotating either towards or from each other; in the first case the eastern hour-angle is decreasing, in the second case the western hour-angle is increasing.

So it follows that the Right Ascension of the (Meridian of the) observer is an ever-varying quantity, being dependent upon the hour-angle of the equinoctial point at any given moment as shewn by his Sidereal Clock.

In navigation books the word "meridian," when used in this connection, is intended to mean *the meridian of the observer;* but as there are many meridians, the omission of the word "observer" may cause perplexity, and therefore—cumbrous though it be—it is here inserted whenever it appears advisable. This Appendix is not intended for astronomers, but for young sea officers anxious to know something more than mere "Rule of thumb."

47. RIGHT ASCENSION OF THE MEAN SUN. The mean Sun is an ingenious creation of the astronomer to meet the requirements of this work-a-day world in general, and of clock-makers in particular. It is a fictitious body which is supposed to make the round of the *equinoctial* with *uniform* velocity in the same time that the real Sun makes the round of the *ecliptic* with *variable* velocity.

Though in the 12-months' race it happens that sometimes one is ahead and sometimes the other—the amount being shewn by the Equation of Time *plus* or *minus*—both suns reach the winning post at the same instant: on the turf this is described as a "dead heat."

We see, therefore, that the apparent revolution of a star round the Earth gives a *day* of uniform length, and that the real revolution of the Earth round the Sun gives a *year* of uniform length.

Mean noon is the instant when the mean Sun is on the celestial meridian of the observer, and mean time is therefore the hour-angle of the mean Sun (*see* pages 397-398).

Now, it being understood what is meant by "mean Sun," it follows from definition No. 45 that the "Right Ascension of the Mean Sun" (written R.A.M.S.) is simply its distance from the equinoctial point at any given moment. But here comes a little complication, for, unlike the R.A. of a fixed star, the R.A.M.S. is a constantly increasing quantity, owing to the mean solar day being longer than a sidereal day by $3^m\ 56{\cdot}56^s$ of *sidereal* time. This means that 24 mean solar hours equal $24^h\ 3^m\ 56{\cdot}56^s$ sidereal hours. The excess is termed the "Acceleration of sidereal on mean solar time."

By opening the *Nautical Almanac* at page II. of any month it will be seen that the right-hand column is headed "Sidereal Time." A very little reflection, based on previous definitions, will convince the student that with equal propriety this column might be headed "Right Ascension of the Mean Sun," for so it is, *but only at the instant of Greenwich mean noon.* For any subsequent hour the Sidereal Time has to be corrected (or brought up to date) by adding the amount of acceleration corresponding to the time elapsed since mean noon. This is an ordinary "rule of three" sum, but even that little trouble is saved by the table on page 778.

To sum up, the R.A.M.S. is nothing more than the Sidereal Time at Greenwich mean noon after correction in the manner already described. In corroboration, please note that the Sidereal Time as recorded in the *Nautical Almanac* increases daily by 3^m $56{\cdot}56^s$. On page 559 are two examples involving the use of the R.A.M.S. *to get Mean Time.* The rule is :—From the Sidereal Time at place (increased if necessary by 24 hrs.) subtract the R.A.M.S. : the result will be Mean Time at place.

48. HOUR-ANGLE, or **Horary-Angle**, or **Meridian Distance**. These all mean the same thing. The second and third ought to be chucked out—especially the third, as it is apt to get mixed up with a similar expression in nautical surveying used to express the difference of longitude between two stations.

The Hour-Angle—like Right Ascension—is also *an angle at the pole*, but in this case it is the angle between the celestial meridian *of the observer* and the hour circle passing through the body in question ; whereas in the case of Right Ascension the angle is between *the zero hour-circle passing through the equinoctial point* and the hour-circle passing through the body.

In other words, the Right Ascension of any given body is its distance in time *from the equinox ;* and the Hour-Angle is its distance in time *from the observer.*

This again amounts to saying that the Hour-Angle is simply the difference between the body's own Right Ascension and the Right Ascension of the Meridian of the observer. But just taking the *difference* will not tell what *name* to give to the Hour-Angle. All sorts of mystification would ensue ; but none whatever by following this simple rule :—*From the Right Ascension of the Meridian (increased by* 24 *hours if necessary) subtract the Right Ascension of the Star : the remainder will be the Hour-Angle West ; if it exceeds* 12 *hours, subtract from* 24 *and name it East.* (*See* pages 129-131).

There is a very simple and graphic way of *shewing* how to name the Hour-Angle—making a mistake impossible. It can be rigged up in less than no time, and costs nothing. The requisites are a piece of whitish cardboard about 7 inches square, and a piece of writing paper somewhat smaller ; also a couple of ordinary brass pins from your wife's or sister's pincushion, or from your own "Ditty-bag."

On the cardboard describe a circle with a diameter of 5 inches ; divide the circumference roughly into 24 hours, marking the 0^h or 24^h with ♈, which is the symbol for the Equinox, or First Point of Aries.* Then the circumference will represent the Equinoctial, and the numerals will be hours of Right Ascension : they must be written down from west to east, as they would be written on this page. If you like to take the trouble, the names of the principal stars may be set down against their respective Right Ascensions. For example, *Hamel* would be written against 2 ; *Capella* against 5 ; *Regulus* against 10 ; *β Centauri* against 14, and so on.

Next, describe a circle of 4½in. diameter on the writing paper, and cut it out neatly with scissors. From the centre to the circumference draw a red line, and write along it "Right Ascension of the Meridian of the observer."

* It looks like a grapnel.

Complete by drawing a few arrows round the margin of the paper circle in the direction of from west to east. The paper will then represent the Earth ready to rotate in the plane of the Equinoctial, which it can be made to do after fastening together it and the cardboard by a pin through their common centre. The " gatchet " is then ready for action.

Now, to *see* what name to give any particular Hour-Angle, you have only to set the red line to the hour representing the Right Ascension of the Meridian, and stick in the second pin at the hour corresponding to the star's Right Ascension : it then speaks for itself.

EXAMPLE :—When the Right Ascension of the Meridian is 22^h, required the Hour-Angle of *Hamel*, and its name. Having set the red line to 22^h, and stuck in the pin against *Hamel*, it is at once seen that the Hour-Angle is 4^h East. Now try how this agrees with the verbal rule :—

	h	m	
R.A.M. of observer...........	22	0	
R.A. of ✱ *Hamel*...........	2	0	subtract.
Hour-Angle.....................	20	0	W.
	24		
Hour-Angle.....................	4^h	0^m	E.

Let the Hour-Angle of *Altair* be required when the R.A.M. is 2^h 0^m. Set the red line to 2^h and stick in the pin at 20^h against *Altair*. The Hour-Angle is 6^h west.

	h	m	
R.A.M. of observer	2	0	+ 24^h
R.A. of ✱ *Altair*...........	20	0	subtract.
Hour-Angle	6^h	0^m	W.

The Hour-Angle, as may be seen by the "gatchet," is measured by the arc of the Equinoctial included between hour-circles of the observer and the body, and is mostly reckoned in Time.

Since it is the result of the unceasing rotation of the Earth on its axis, the H.A. is continually changing in amount : at each instant easterly Hour-Angles grow smaller, and westerly ones grow larger.

With the Sun all is plain sailing, since it is obvious that a P.M. Hour-Angle is the same as Apparent Time at Ship ; and an A.M. Hour-Angle is got by subtracting Apparent Time from 12 hrs.

Further light may be thrown on the subject by explaining how in practice Mean Time at Ship can be got from the Hour-Angle of a star.

1. Given the Hour-Angle and time by chronometer.
2. Find the corresponding Greenwich Date.
3. Take out star's R.A. from *Nautical Almanac.*
4. Take out Sidereal Time at *preceding* Greenwich Mean Noon, and correct it for Greenwich Date by table on page 778. *It then becomes the Right Ascension of the Mean Sun.*
5. When the Hour-Angle is *West, add* it to the star's R.A. : this gives *the Right Ascension of the Meridian of the observer :* from this (increased by 24 hrs. if necessary) subtract the R.A. of the Mean Sun, and the result will be Mean Time at Ship.

6. When the Hour-Angle is *East*, subtract it from the star's Right Ascension (increased by 24 hrs. if necessary). This gives the R.A. of the observer's meridian: then proceed as before. Two examples are given on page 559.

NOTE.—It simplifies matters to regard *all* Hour-Angles as *Westerly*. By subtracting an Easterly H.A. from 24 hrs. it becomes a Westerly one: Rule 6 is then not needed. Try the experiment with *Fomalhaut*, on page 559.

A study of Nos. 37-48 makes it clear that in Nautical Astronomy there are two principal points of departure from which intervals of time are reckoned, viz.:—The Vernal Equinox (or First Point of *Aries*), and the Meridian of the Observer. The Vernal Equinox is concerned with Sidereal Time and Right Ascensions; and the Meridian of the Observer has to do with Hour-Angles.

When the object is on the meridian the Hour-Angle is zero.

49. DIURNAL CIRCLES. To get a correct idea of the movements of the heavenly bodies these circles should be closely studied: the knowledge thus acquired will be found most valuable to anyone who aspires to being a really crack navigator.

If the heavens be watched for a few hours on any fine night—and sailors, above all other men, have heaps of opportunities—one cannot help noticing that while certain stars rise somewhere along the eastern horizon, others set somewhere along the western horizon, and that all move in circles *uniformly* in such a way as not to disturb their relative configurations, but as if they were attached to the inner surface of a hollow rotating sphere, turning on its axis once a day (sidereal).

The path thus described by any one star *during a complete revolution* is called its Diurnal Circle. In the case of the Sun, the portion *above* the horizon is termed its "diurnal arc," and the portion below, its "nocturnal arc."

The *apparent* motion of the heavenly bodies from East to West is caused by the steady left-handed rotation of the Earth in the opposite direction. This teetotum-like spin is at the rate of nearly 17·3 statute miles a minute at the Equator. Expressed in arc it is 15′ per minute, or 15° per hour; making, of course, 360° in 24 hours (sidereal). In 24 hours of *Mean* Time the Earth rotates through 360° 59′ 8″·33, and a *mean solar* day is therefore longer than a *sidereal* day by 3^m $56{\cdot}56^s$ of *sidereal* time.

If we express it in *Mean* Time, the length of a Sidereal Day is 23^h 56^m $4{\cdot}09^s$.

But to revert to the *aspect* of the heavens:—If the observer faces south, the *apparent* motion of the heavenly bodies is right-handed; if he faces north, it is left-handed.

It is obvious, even from the little here said, that there must be a great variety of Diurnal Circles according to the declination of the body and the latitude of the observer—the place of the pole in the sky depending upon the latter. It will presently be shewn that the place of the pole is the governing factor where Diurnal Circles are concerned.

We will try to illustrate this by putting the observer in the two extreme positions of the Equator and the Pole, and depicting what would be the aspect of the heavens from each of these points of view. We will begin with the Equator. *Note.*—The student would derive *great assistance* from a celestial globe.

50. THE RIGHT SPHERE. With the observer at the Equator (Lat. 0°), the celestial poles will be in his horizon bearing respectively north and south; and the celestial equator (or "equinoctial") will pass vertically overhead through his zenith in an east and west direction. It will therefore be identical with the prime vertical.

Do not forget that the altitude of the pole equals the latitude of the observer; consequently, if the latitude be 0°, the altitude of the poles must also be 0°, which is equivalent to saying that they are in the horizon. (*See* pages 366, 367).

Stars of *any* declination short of 90° N. or S. will rise and set vertically, and their Diurnal Circles—*however large or small*—will be bisected by the horizon, so that they will be exactly 12 hours above it and 12 hours below. With the exception of such stars as have declination 0°, the Diurnal Circles will be "small circles."

Now let us imagine the stars to be *really* moving across the sky from east to west, and that each of the more conspicuous ones marked its path by leaving a permanent trail of light in its wake; then the observer at the equator, looking towards one or other of the poles, would see an irregular series of concentric semicircles—one within the other—getting smaller and smaller towards the poles. It would be as if he were standing exactly in the centre of a straight railway tunnel, with ribbed arches, and of such a length that the openings at either end were reduced to a mere speck of light. The specks of light would be the north and south Celestial Poles, and the ribbed arches, at varying distances apart, to suit the varying declinations, would represent the upper halves of the Diurnal Circles. The railway tunnel is here assumed to be a true semicircle; but it is in fact always *more* than a semicircle, the hidden portion underneath the line being called the "invert." This is *not* Nautical Astronomy, but merely a remark in passing.

51. THE PARALLEL SPHERE. The other extreme, and still more unlikely case, is when the observer is at one of the Poles of the Earth (Lat. 90°).

He who reaches this mathematical point—for convenience let us say the *North* Pole—will find himself confronted with some strange phenomena. For example, the elevated celestial pole will be exactly in his zenith, and the equinoctial will coincide with the horizon. All stars of northern declination will remain *at a fixed altitude* above the horizon—neither rising nor falling—but perpetually sailing round in "small circles" parallel to the horizon. He has only to slue round on his heel to see at one go every star in the Northern hemisphere. On the other hand, stars (not planets) belonging to the Southern hemisphere would *never* come into view.

To the man at the North Pole there would be no north, east, or west points—nothing but *South* in every direction, and the heavenly bodies whilst visible would always be on a meridian. So long as our man stood motionless the rotation of the Earth on its axis would simply turn him round on a pivot, like a wax figure in a hair-dresser's window. His weight also would be increased by about a pound, owing to being 13½ miles nearer the Earth's centre than when he was at the equator.

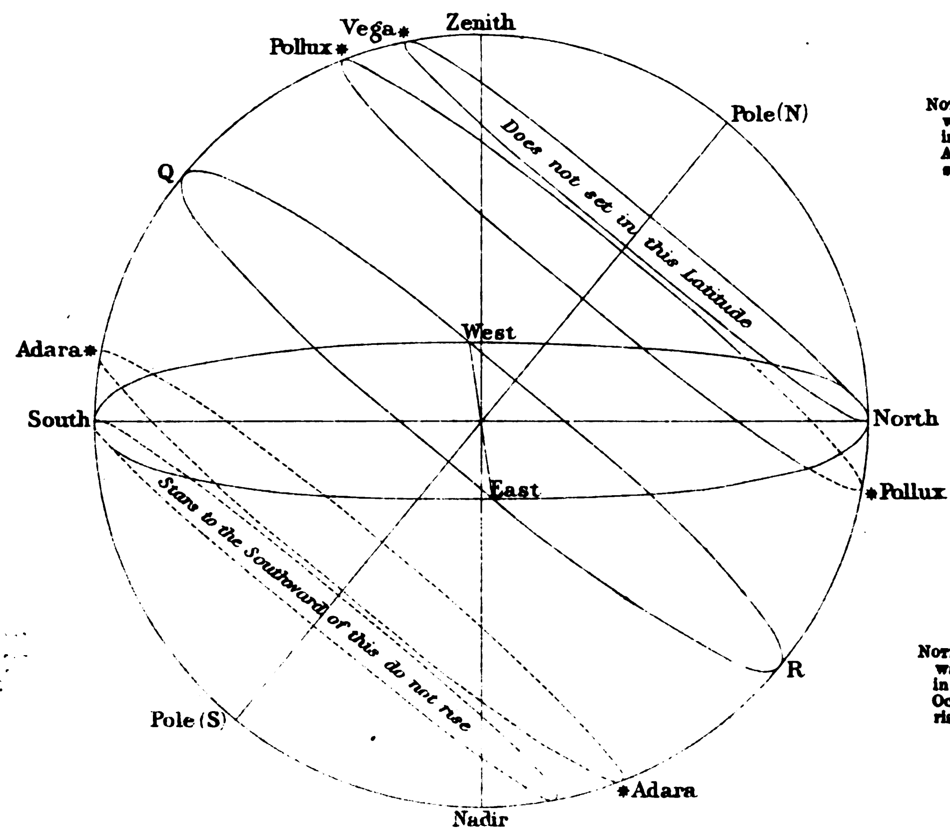
Should he remain for a year (and one can fancy him saying "Heaven forbid!") he would have during that time but one day and one night—long ones, to be sure, for each would be of six months' duration. On March 20th the upper limb of the Sun, preceded for a week or so by a day-dawn glow, would top the horizon, and, as it travelled round, more and more of it would slowly come into view, until on the following day the entire disc would be visible, and the "orb of day" would present the curious appearance of a ruddy ball rolling round the horizon.*

Day by day the Sun would mount higher, slowly describing a flattened spiral in the heavens, till on June 21st it would attain the maximum altitude of 23½° with a Right Ascension of 6 hours. After that it would depart in reverse order, till on September 22nd, with a R.A. of 12 hours, its centre would again be on the horizon, and the following day it would disappear in the same lingering manner as it came, leaving winter behind for an unbroken period of six long months, during which the chief compensation would be the auroral displays and the bi-weekly visits of the Moon.

But before the Sun bids farewell to the summer solstice, it is worth while to call attention to what would happen if the individual at the pole were to *take a step or two towards* that luminary. By so doing he would at once make it "*noon* or *mid-day*." Having accomplished this very easy feat, let him "right about turn" and march a few paces *from* the Sun so as to get on the *opposite* side of the pole. It would now be *midnight*, notwithstanding the absence of darkness; in fact, our Polar Sentry would have it in his power to create for himself at will the phenomenon of the "Midnight Sun," which for some years past has taken so many tourists to the North Cape at midsummer. As often as he chose, and with the minimum of exertion, the man at the pole would be able at one moment to view the Sun on the meridian at its *upper* culmination, and at the next to see it at its *lower* culmination; thus annihilating time and space, and upsetting our established notions of the decorous behaviour of the celestial bodies. In other words, a couple of strides would change astronomical noon into astronomical midnight. This knocks Maskelyne and Devant into fits.

We will now consider the *Moon's* behaviour. Like the Sun, our satellite spends an equal amount of time in each hemisphere; but, owing to the very much greater rapidity of her motion, the Moon would be visible and invisible during alternate fortnights. In these ice-bound regions, she would more especially deserve her name of "the cold chaste moon;" but depend upon it she would nevertheless be right welcome when she came. She would shew her appreciation of the reception accorded her by remaining visible to the watcher during the whole period of her visit; like the Sun, there would be no daily rising and setting.

* The hourly change in the declination, and therefore hourly increase in the altitude, is nearly one minute of arc (1′) when the Sun is "crossing the line." This rate gradually diminishes to zero at the solstices.



NOTE.—Stars to the northward of 51° 20′ N. lie within the circle of Perpetual Apparition and do not set.

NOTE.—Stars to the southward of 38° 40′ S. lie within the circle of Perpetual Occultation and do not rise.

Oblique Sphere for Lat. 51° 20′ N. showing diurnal circles of Vega (decl. 38° 42′ N.), Pollux (decl. 28° 16′ N), and Adara (decl. 28° 50′ S.); also circle of Perpetual Apparition as described by * Vega, and corresponding circle of Perpetual Occultation in the southern hemisphere

TO FACE PAGE 752

There is just one other point before we finish with the sentinel at the pole. Though the Sun is invisible for six months, it must not be supposed that during all that time the watcher is shrouded in black night. It has been shewn that the silvery Moon makes regular visits at short intervals, and of course there is starlight also. Moreover, the flashing "Northern Lights" are a sight not easily forgotten. But over and above these luxuries, there is something besides which proves that an often heard of sable personage is never *quite* so black as he's painted.

Owing to the refraction and reflection of light, a certain amount is received from the Sun even when *below* the horizon, and this is the case so long as the Sun is not more than 18° below it. When this downward point has been passed, twilight ceases altogether, and darkness (so far as the Sun is concerned) reigns supreme. Of course the degree of twilight depends upon *how far* the Sun is below the horizon. It goes without saying that at 6° below, the twilight would be stronger than at 16°. Now the Sun does not reach 18° S. declination till the middle of November; and on returning northward it again reaches 18° S. about the end of January: therefore, excepting for some three months at midwinter, the man at the North pole has always more or less twilight. After all, then, and aided by his white surroundings, he is not so badly off in this respect as most people would imagine. Perhaps, also, it may be a source of satisfaction to know that even in his darkest moments the sailor's guiding star (*Polaris*), like the proverbial "sweet little cherub that sits up aloft to look after poor Jack," is serenely looking down upon him from a point almost right overhead.

52. THE OBLIQUE SPHERE (*see* Plate). Since but few people reside permanently, or even temporarily, on the Equator, and fewer have succeeded in capturing either Pole, this—of the Olique Sphere—is the aspect of the heavens which, weather permitting, nightly presents itself to the great majority of earth-dwellers. The Oblique Sphere is, and always will be, the one to engage the attention of most seafarers. We must therefore take more than ordinary pains to set forth its peculiarities.

To prevent confusion, and to get away from mere generalities, we will, throughout what follows, assume the learner to be located at some spot intermediate to the equator and the *north* pole: then at any such spot the heavenly bodies (of all denominations) will move in circles *oblique to his horizon*, and the higher the latitude the greater will be the obliquity, the exact angle from the zenith being arrived at from the simple fact that it is equal to the latitude. We have seen that to the observer at the equator stars rise and set *vertically;* and that to the observer at the poles, stars move round *horizontally* without either rising or setting: therefore, at intermediate stations, such as we are now considering, they must move *obliquely* to the horizon, which is the correct translation of the American word "Slantin-diklar."

For greater convenience we will deal exclusively with the movements

* Written in July, 1899.

of the stars, it being understood that other bodies—so far as their limited declinations permit—behave in a manner precisely similar.

In his new position the observer will notice a tendency of stars to linger near the horizon (not that there is any real reduction of speed) before sinking into the depths beyond; and those with *north* declination which may pass the meridian to the *southward* of his zenith will nevertheless rise and set behind him, so to speak, or to the *northward* of the east and west points. This last feature always puzzles the novice, who, not realizing the *obliquity* of the diurnal circles, almost invariably thinks that a star whose declination is less than his own latitude should rise and set to the *southward* of the E. and W. points, and accordingly, at such times, looks for them in the wrong place.

The next thing to point out is that stars north of the equator will have *more than half* their diurnal circles *above* the horizon, and will therefore be visible for *more* than 12 hours. (*See* footnote, page 316.)

To exemplify the oblique movement by actual figures capable of verification, let the latitude be 51° 20′ N., which fits in fairly well with a number of places on our own coasts, such as the Fastnet, the Breaksea Lightship near Cardiff, or the Downs near Ramsgate; but the open sea is preferable, as giving an unobstructed horizon to the north. Now, being in this latitude in *any* part of the Northern Hemisphere, let the observer put on his warmest monkey-jacket, woollen mitts, muffler, and sea-boots, for the date is January 13th, 1902, and lay himself out to follow the course of the bright and easily recognised *Pollux*, whose declination—28° 16′ N.—puts it nearly half way 'twixt himself and the equator. It will be a long watch, so he and a sympathetic brother officer can take it in turns, and report progress to each other. Participation will increase the interest: it is chummy, and means mutual instruction, which happens to be the very best way of learning.

When on the meridian about midnight (Apparent Time at Ship), the angular distance of *Pollux* to the *south* of the observer's zenith will be 23° 4′; nevertheless, it will rise 49¼° to the *north* of east, and set at the same amplitude to the *north* of west. It is evident that, to accomplish this, its path in the sky must be a slanting one from north towards the south when rising, and the reverse after passing the meridian.

A rough and ready way of shewing this is to borrow the horse-shoe—there is certain to be one for luck somewhere about the ship, the proper place being *on*, not *in*, the harness cask—and on your tobacco-board (*see* page 542) draw a circle (in chalk will do) a couple of inches or so greater in diameter than the distance between the points of the horse-shoe. This circle is meant for your own horizon, its centre is your own position, and its further side represents the south. From left to right, through the centre, draw a straight line (diameter) to represent the Prime Vertical: its extremities will of course be the E. and W. points. Next stick a pen, pricker, roping needle, a lady passenger's stiletto, or anything that comes handy, into the centre of the circle, and fix it as upright as you can: this will shew the direction of the zenith.

All you have now got to do is to hold the legs of your lucky horse-shoe on the nearer semicircle, about half-way between the prime vertical line and the part of the circumference nearest to yourself; next lean the *top* of the horse-shoe *from* you to such an extent that it may be 23° by guess to the south of the pricker. The representation is then complete. The left leg of the shoe will represent the spot where *Pollux* will rise, the top of the shoe the meridian altitude, and the right leg the place of setting. If your eye is a good one for making measurements, you might even roughly guess the altitude when on the prime vertical; this is 37° 20′ at 4^h 18^m, on either side, from the meridian. (*See* Table 29 of *Raper*.)

Now, as *Pollux* passes the meridian about midnight on the 13th January, 1902, it will be on the prime vertical bearing east at 7^h 42^m P.M. on that day, and bearing west at 4^h 18^m A.M. on the 14th.

Pollux will be 17^h 38^m *above* the horizon, and 6^h 22^m *below* it. So on January 13th it will rise about 3^h 11^m in the afternoon, and set at 8^h 49^m the following morning. This completes all the points of interest in connection with the movements of *Pollux*, as presented to an observer in the given latitude and on the given date. Other northern stars passing the meridian to the southward of the observer will behave somewhat similarly, according to their respective declinations. An example showing one of a special character will be given further on.

Stars of southern declination, though conforming to the same oblique movement, will spend *less* than 12 hours *above* the horizon, and *more* than 12 hours *below* it. To prove this let us choose *Adara*, with declination 28° 50′ S., which is nearly the same as that of *Pollux*, but of opposite name. To the observer in 51° 20′ N., *Adara* will rise 50½° to the *southward* of east, will pass the meridian 80° 10′ to the *southward* of his zenith, and will set 50½° to the *southward* of west. It will be *above* the horizon for only 6^h 12^m, and *below* it for 17^h 48^m; just reversing as nearly as possible the behaviour of *Pollux*.

Now, if stars of northern declination act in one way, and stars of southern declination act in the contrary way, there must somewhere be a neutral line where the change takes place. This neutral line is the Equator, for there the diurnal circle of a star whose declination is 0° will be exactly cut in two by the horizon, and such star will be above the horizon just as long as below it, namely, 12 *sidereal* hours, equal to 11^h 58^m of mean solar time.

Next we come to **circumpolar stars**. Strictly speaking *all* stars are circumpolar, but it is convenient that the expression should be restricted to those *whose distance from the elevated pole is less than the observer's latitude.* Such stars never sink below the horizon *of that place*, and consequently, with a suitable instrument (the Equatorial of an observatory), their diurnal circle can be followed "from start to finish," if such a phrase can be used of a figure which has neither beginning nor end.

Keeping the star-gazer still planted in Lat. 51° 20′ N., we will now invite his attention to the brilliant *Vega* (declin. 38° 42′ N.). This star, though passing the meridian nearly 12⅔° to the *southward* of his zenith, will just come within the category of "circumpolar," for 11^h 58^m after passing the meridian—when at its lower culmination—it will be found just skimming the *north* point of the horizon. (Refraction not considered.) The diameter of *Vega's* diurnal circle would be large in this latitude—102° 36′—and of course in an observatory the whole of it *could* be followed continuously, weather and patience permitting.

As the polar-distances of stars diminish, so will the diameter of their diurnal circles, until at last *Polaris* is reached with the smallest diurnal circle of all those in which the sailor is interested. After *Polaris* comes the polar point itself, and this, being a fixture in declin. 90°, has no diurnal circle whatever.

Circumpolar stars, being always above the horizon, lie within what is called the **Circle of Perpetual Apparition,** the radius of which is equal to the altitude of the pole, which again is equal to the latitude.

Per contra, stars at similar distances from the depressed pole lie within the "**Circle of Perpetual Occultation,**" and never come into view. In this way we in England are precluded from seeing some of the brightest of the southern constellations. The size of these two circles depends entirely upon the latitude, but whether large or small, they are always counterparts of each other. When the observer is at the Pole, they are a maximum; when he is at the Equator they cease to exist.

From the foregoing we see that to understand the movements of the heavenly bodies requires considerable study—but nothing more than *any* one is capable of. A voyage from England round the Horn includes all the possibilities of the "*Oblique Sphere,*" but a shorter cut is obtained by the use of a decent-sized *celestial* globe, say, one of 24 inches: owing to cost, it is not often that larger ones are met with. To "rectify" the globe for the *Oblique Sphere*, the elevated pole must be raised and adjusted to an angle equal to the desired latitude—say 51° 20′, as we have just been dealing with it. This can be done by means of the degrees marked on the brass meridian; then by rotating the globe from east to west it will readily be seen what stars never set, which ones never rise, and during what part of the 24 hours any given one is above or below the horizon, together with its meridian zenith distance and amplitude.* The data given for *Pollux* and *Adara* can be put to the test, and thus confidence will be acquired in a very short time.

To give a correct idea of the movements of the stars, there is nothing that can touch the celestial globe. Once the student has mastered the subject—and it won't take him long—practical star work will come much easier, and prove ever so much more interesting and useful. Knowing the path any given star *must* follow according to *its* declination, and *his own* latitude, he will always know where to look for it, and identification will be but the work of a moment. Many men are loath to touch stars for *longitude*, because of the Hour-Angle being treated differently to that of the Sun. The difficulty is wholly imaginary; there is really nothing in it, and a perusal of Definition No. 48 will show how supremely simple it becomes in practice. As for the remainder of the work, it is no more than for the Sun, seeing that the Declin. does not require to be corrected; both it and the star's R.A. are taken out at sight, and at the same opening. Like the Sun also, the Altitude correction is found by inspection from a Table given in every epitome.

Where, then, is the difficulty?

* Recollect that we are now dealing with the *Celestial* Sphere, which seems to revolve in this manner because of the real rotation of the Earth in the opposite direction.

APPENDIX (O).

LUNARS *versus* CHRONOMETERS.

The following amusing lines from the facile pen of Mr. E. Plumstead appeared in the March number of the *Nautical Magazine* for 1900. They are inserted by kind permission of their author, and of the editor of the *N. M.* Mr. Plumstead appears to be an exceptionally good observer, whether in fine weather or foul. As a yachtsman he takes unusual interest in the science of Navigation, making a specialty of the "Lunar," which—blow high, blow low—he never tires of pushing to the front. Whilst deprecating the tabooing of the Moon for determination of position, Mr. Plumstead is in other respects an ardent champion of "Wrinkles," which he has facetiously dubbed "The gospel according to Lecky"; the writer is at once grateful and flattered. But as regards the no longer vexed question of "Lunars *versus* Chronometers," the average professional Navigator has long ago decided it for himself, and not even the eloquent advocacy of so enthusiastic and capable an amateur will move him. The one knows the peculiar secrets of the sea—the other does not. Unfortunately, Navigation happens to be one of the least of the multifarious duties of the great bulk of Shipmasters: *vide* ending of Preface to First Edition.

THERE was a time when Parallax and dear old Mrs. Moon
Were understood by seamen, and esteemed a precious boon.
Then *Wrinkles* came; Edition Nine burst forth mid jubilation,
Waxed fat and kicked; and then ensued the following conversation:

"Pack up! Clear out!" said *Wrinkles*, "Take notice now, and mind,
Both Parallax and you to Coventry we've consigned."
"Who's *We?*" retorted Mrs. Moon, "I never heard such fudge;
Are you the We? Have I no friends? Are you the only judge?"

"You've hit it off," said *Wrinkles* "I *am* the We, far famed:
You've lost your ancient following, of your conduct they're ashamed,
Except a few 'Old Timers,' who from sundry dark recesses
Sing your praises in the papers, have no names, give no addresses."

"That's rather neat," replied the Moon, "But will you have the kindness
Just to state the cause of this revolt, and why this modern blindness
To the virtues that I still possess? Explain the situation.
What has blighted all my virtues? Who has spoiled my reputation?"

"Where have you been? What have you learned?" said *Wrinkles*, "Don't you know
What happened here—it must be near a century ago?
You've heard of Sextant, Compass, Log, Mercurial Barometer;
Tremble! a goddess has been born. We've christened her Chronometer.

"Behold my love, is she not fair? so strong, so plump, so pliable."
"All Tommy Rot," replied the Moon, "I'll bet she's not reliable"
"Alas!" said *Wrinkles*, "I know that; for has it not been noted,
To her most eccentric conduct my best chapter's been devoted?

"Had you but read what I have said on her merits and demerits
In Chapter Four, not for one hour would you maintain your spirits;
Could I but show you *Wrinkles* your appearances would cease,
You'd for ever hide your 'bloomin' cheek,' for ever hold your peace.'

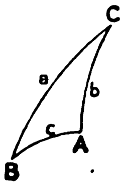
"Of *Wrinkles*, sir," replied the Moon, "We've 'several copies' here;
But the chapter headed Lunars is the one we hold most dear.
With equal care we've read them both; compared our notes, and reckoned
No mortal who believed the first could understand the second.

"'Tis just about twelve months ago, I said to some inquirers,
'You had no power to banish me, I still have my admirers.'
Adieu! dear boy. I'm off. Good night. To Coventry? *No! Never!*
Let 'Wrinkles' come, Chronometers go, but I go on for ever."

Lunars expensive, a source of cramming, and impracticable.

Much has happened since Mr. Plumstead penned his humorous poetical defence of the lunar-distance method. The *Nautical Almanac* for 1907 (both editions) is without tables of lunar distances, and, after 1906, not even candidates for the misnamed "extra" master's certificate have been required to shew arithmetical accuracy by working an old-fashioned lunar. By the aid of the tables of Right Ascension and Declination, which are continued in the *Nautical Almanac*, a leisured lunarian of phenomenal perseverance can calculate the omitted lunar distance for himself; but lunars are as much out of date as the caravels of Columbus—and for a like reason. Once reliable chronometers were on the market at a moderate price, the time-honoured lunars were doomed as regards the purposes of practical navigation; and they naturally fell into desuetude, even as safeguards against navigators' negligence or mechanical mischief. For a very long series of years lunar distances were given in the *Nautical Almanac* with a persistency worthy of a better cause, and the lunar formed part of the so-called "extra" examination; although it was well known that the former was never, or hardly ever, used by practical navigators for various well-founded reasons, while the arithmetical test in an examination room was often brought to a successful issue by men who had never measured a lunar distance by sextant, who could not if they would, and who would not if they could. The computation of lunar distances at the expense of the nation was unnecessary, and the inclusion of the lunar in Board of Trade examinations gave plenty of scope for the honest doubter as to their utility, inasmuch as it did but encourage cramming of a most baneful character. To find a lunar distance we have given the polar distances of the two heavenly bodies as the sides of a spherical triangle, and the difference in Right Ascension as the included angle, to find the third side. This is precisely the same thing as finding the distance on a great circle between two ports on our planet. A type of the method to be followed is worked in the *Nautical Almanac*, for the Moon and Spica; but there is not any necessity to find the spherical angles at the base of the figure, and the direct method of solution is strongly recommended. In the spherical triangle ABC, let C be angle = difference of right ascensions, BC = a = the greater polar distance, AC = b = the lesser polar distance, and AB = c = the lunar distance sought; then the formula to be used, with the assistance

Similarity of lunar distance and great circle calculation.



of an auxiliary angle θ, are: (1) tan. θ = tan b cos. C, and (2) cos. c = cos. b cos. $(a - \theta)$ sec. θ.

In the *Nautical Almanac* example: C = 23° 26′ 18″ = Moon's R.A. − Star's R.A.; a = south polar distance of Spica = 79° 19′ 26″; b = south polar distance of the Moon = 78° 16′ 26″. Then it will be found that θ = 77° 15′ 9″; $(a - \theta)$ = 2° 14′ 17″; and c = lunar distance required = 23° 0′ 30″.

Method of working.

To Find *C*.

b tan.	0·68285	b cos.	9·30799
C cos.	9·96260	$(a - \theta)$ cos.	9·99972
		θ sec.	0·65629
θ tan.	0·64545		
		c cos.	9·96400
$\therefore \theta$ = 77° 15′ 9″			
		$\therefore c$ = 23° 0′ 30″	

England has followed the lead of France in the matter of lunars. In 1902, the French Bureau of Longitude announced officially that from, and after, 1905 the *Connaissance des Temps* (French *Nautical Almanac*) would cease to publish the hitherto usual tables of lunar distances. One of the members of the Bureau—M. E. Guyou, Capitaine de frégate—dealt fully with the past, present, and future of the lunar, in an article of some length, which may be found in the *Revue Maritime* of June, 1902. These tables had been regularly given for 131 years in the *Connaissance des Temps*, and for 140 years in the *Nautical Almanac;* but they have disappeared in tardy agreement with the inexorable law of the survival of the fittest. After quoting the condemnation of the lunar by *Wrinkles*, Captain Guyou expressed the opinion that the justice of the revolutionary opinion there given so emphatically cannot be logically contested.

France follows Lecky, and England follows France, in condemning lunars.

The foundation of Greenwich Observatory in 1675, under Flamsteed, led to a rectification of the lunar tables, in accordance with the terms of his appointment; in 1713 the illustrious Newton's tables were published; and improvement, not only in lunar tables, but also in instruments for measuring the lunar distance at sea, has been continuous. At the same time the demand for both tables and instruments has fallen far in defect

Lunar tables

of the supply. A tyro in navigation, or nautical astronomy, can readily grasp the minutiæ of the lunar distance problem. None but an observer of experience in this particular branch may rightly hope to measure a lunar distance correctly. Consequently, the "extra" master devoted his attention to the "figgers" required of him by the examiners, and calmly ignored the practical part of the work, which is absolutely necessary. Comment is needless!

Greenwich Observatory

Greenwich Observatory was originally destined for the purpose of obtaining large numbers of accurate observations of the positions of the moon and the stars near her path, in order to be able to predict, with some degree of certainty, their distances at specified hours of Greenwich mean time. The first Royal Observatory cost but £520, and the salary of the first Astronomer Royal was but £100 per annum, a sum which barely paid for his instruments. To conclude, Greenwich Observatory came into being solely for the benefit of seafarers, and excellently was this purpose fulfilled. Like other public institutions, however, founded solely for seamen, the shore-dweller has practically absorbed it.

Advocacy of the lunar—able but misplaced.

Those who still regard the lunar with affection cannot do better than obtain back numbers of the *Nautical Magazine*, say from 1900 to 1905, both years inclusive, which contain very able articles in favour of the retention of the method, by Mr. H. B. Goodwin, R.N., and Mr. E. Plumstead. Never has the case for the moon been more clearly, or more enthusiastically, set forth than it was in the contributions from the facile pens of those writers. We repeat, however, that lunars have had their day. Let them rest in peace!

Lord Dunraven's judicial summing up

Lord Dunraven, in his text-book on navigation, has put the case against the lunar problem very fairly. "The most that can be said in favour of lunars," writes Lord Dunraven, "is that, if a great number of them are taken under very favourable circumstances, by a practised hand, fairly accurate results may be expected. It is even just conceivable that a first-rate observer, availing himself of frequent and good opportunities of taking distances during a voyage of many months, might succeed in arriving at a tolerably good estimate of his chronometer's rate; but I would not like to rely upon it. However, we need not bother our heads about whether lunars are useful or not. You need never work one at sea unless it amuses you to do so." *Sic transit gloria mundi.*

EXPLANATION OF SIGNS AND ABBREVIATIONS.

Adopted in the Charts issued by the Hydrographic Office, Admiralty.

QUALITY OF THE BOTTOM.		GENERAL ABBREVIATIONS.			
b. -	blue	Alt. - -	Alternating	Lt. F. -	Light Fixed
blk. -	black	Near a Light. Anchge. -	Anchorage	Lt. Fl. -	Light Flashing
br. -	brown	B. - - -	Bay	Lt. Int.	Light Intermittent
brk. -	broken	B. - -	Black	Lt. Rev.	Light Revolving
c. - -	coarse	Near a Buoy. Baty. -	Battery	L.W. - -	Low Water
cl. -	clay	Bk. - -	Bank	Magz. -	Magazine
crl. -	coral	C. - - -	Cape	Magc. -	Magnetic
d. -	dark	C.G. - -	Coast Guard	Min. - -	Minutes
f. - -	fine	Cath. - -	Cathedral	Near a Light. Mt. - -	Mountain
g. - -	gravel	Ch. - -	Church	Np. - -	Neaps
gn. -	green	Chan. -	Channel	Obsn. Spot	Observation Spot +
grd. -	ground	Cheq. -	Chequered	P. - - -	Port
gy. -	gray	Near a Buoy. Cold. - -	Coloured	P.D. -	Position doubtful
h. -	hard	Cr. - -	Creek	Pk. - -	Peak
m. -	mud	E.D.	Existence doubtful	Pt. - -	Point
oys. -	oysters	Flg. Lt. -	Floating Light	R. - - -	River
oz. -	ooze	Fms. - -	Fathoms	R. - - -	Red
peb. -	pebbles	Ft. - -	Feet or foot	Near a Buoy. Rf. - -	Reef
r. - -	rock	G. - -	Gulf	Rk. - -	Rock
rot. -	rotten	Gt. - -	Great	Sd. - -	Sound
s. -	sand	H. - -	Hour	Sec. - -	Seconds
sft. -	soft	Hd. - -	Head	Near a Light. Sh. - -	Shoal
sh. -	shells	Ho. - -	House	Sp. - -	Springs
spk. -	speckled	Hr. - -	Harbour	Str. - -	Strait
st. -	stones	H.S. -	Horizontal Stripes	Tel. - -	Telegraph
stf. -	stiff	Near a Buoy. H.W - -	High Water	Varn. - -	Variation
w. -	white	H.W.F. & C.	High Water Full & Change	Vil. - -	Village
wd. -	weed	I. - - -	Island	Vis. - -	Visible
y. -	yellow	Is. - - -	Islands	Near a Light. V.S. -	Vertical Stripes
gl. -	globigerina	Kn. - -	Knots	W. - -	White
pt. -	pteropod	L. - - -	Lake	Near a Buoy. W. Pl. -	Watering Place
rad. -	radiolaria	Lat. - -	Latitude	Occ. - -	Occulting
for.	foraminifera	Long. -	Longitude	Near a Light. F. Fl. -	Fixed & Flashing
		Lt. - -	Light	Near a Light. L.B. - -	Life Boat
				L.S.S.	Life Saving Stn.

GENERAL REMARKS.

All Charts and Plans are, where practicable, constructed upon the True Meridian—*i.e.*, the East and West marginal lines are drawn parallel to the True Meridian. Soundings are reduced to mean Low Water of Ordinary Spring tides, and are expressed in Fathoms (of 6 feet) and fractions of a fathom, or in feet and fractions of a foot, such being denoted on the Chart. The underlined figures on the dry banks represent in feet or fathoms the depth of water over them at High Water, or the heights of the banks above Low Water. The method adopted is explained in the Title of the Chart.

The Velocity of Tide is expressed in knots and fractions of a knot. The Period of the Tide being shown thus—1st Qr., 2nd Qr., 3rd Qr., 4th Qr., for 1st, 2nd, 3rd, and 4th Quarters; or by I h., II h., &c., for 1st, 2nd, &c., hours after high or low water, or by black dots on the arrows, *e.g.*, two dots on the flood tide arrow ( ) indicates two hours after low water.

The Rise of Tide is measured from the mean Low Water level of Ordinary Springs. The Range of Tide is measured from the Low Water of one tide to the High Water of the following tide.

All heights are given in feet above High Water Ordinary Springs, and in places where there is no tide, above the sea-level.

All bearings, including the direction of winds and currents, are Magnetic; except when otherwise expressed. Bearings of Lights are given as seen from seaward, and not from the lights.

The natural Scale, or the proportion which the Chart bears to the earth, obtained by reducing the number of feet in the minute of latitude to inches, and dividing the product by the number of inches to a mile the Chart is drawn upon, is represented thus: $\frac{1}{12150}$. A Cable's length is assumed to be the 10th part of a sea-mile or equal to 100 fathoms. It has been suggested that soundings on Charts shall always be given in feet, not in fathoms. On page 71 of Knight's *Modern Seamanship*, 1912, it is urged that a "lead-line should have a mark for every fathom and half-fathom up to ten fathoms; and for a considerable range—covering the depths that are critical for the ship using it—it should be marked in feet." For a ship drawing 20 feet of water there would be a mark at every foot between 20 and 30; and the soundings reported similarly by the leadsman. Commander G. P. Chase, also of the United States Navy, has voiced a like opinion.

APPENDIX (Q).

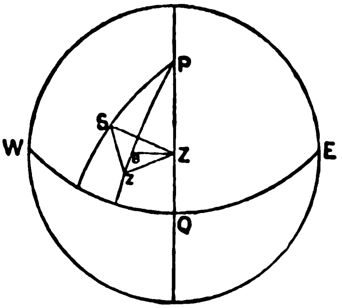


Fig. 1.

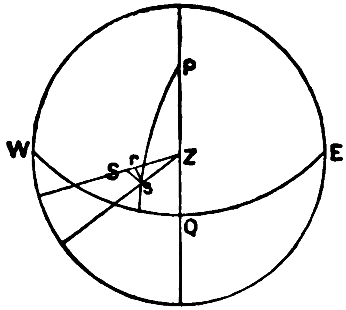


Fig. 2.

The attainment of the values A, B, C, D is as easy as falling off a log to all familiar with the principles of parallel sailing and the most elementary plane trigonometry; bearing in mind that we can often do by a little contriving what cannot be done by pushing and striving. In Fig. 1, projection on plane of horizon, much out of proportion to show small quantities, P = pole; Z, z, the true and erroneous zeniths, respectively; S, the heavenly body; EQW, the equator; SPZ, the hour-angle = H; PZS, the azimuth = A; l = latitude; $d\,l$ = error in latitude; d H = error in hour-angle; δ = declination. With centre P, radius PZ, describe arc BZ. Then, as seen by Fig. 1, Bz = error in latitude = $d\,l$; and ZPz = error in hour-angle = d H. From parallel sailing we recognise that BZ = d H cos. l...(I.). Since the triangle ZBz is extremely small, we may regard it as plane without fear of appreciable error. Then Bz = BZ tan. BZz = BZ tan. PZS...(II.); because PBZ = 90° = SZz, and SZB is common. Therefore, substituting in (II.) the value of BZ given in (I), we have—

$$\begin{aligned} \text{Bz} &= d\,\text{H cos. } l \text{ tan. PZS.} \\ \therefore d\,l &= d\,\text{H cos. } l \text{ tan. A.} \\ \therefore d\,\text{H} &= d\,l \div \text{cos. } l \text{ tan. A.} \\ &= d\,l \text{ sec. } l \text{ cot. A...(III.)} \end{aligned}$$

But cot. A = cot. H sin. l − cos. l tan. δ cosec. H, by elementary trigonometry, and, substituting this value of cot. A in (III.), we get—

$$\begin{aligned} d\,\text{H} &= d\,l \text{ sec. } l \text{ (cot. H sin. } l - \text{cos. } l \text{ tan. } \delta \text{ cosec. H)} \\ &= d\,l \text{ (cot. H tan. } l - \text{tan. } \delta \text{ cosec. H)} \\ &= d\,l \text{ (tabular A} - \text{tabular B)} \end{aligned}$$

Let $d\,l$ = 1; then d H = A − B as per tables.

From (III.) we have cot. A = $\frac{d\,\text{H}}{d\,l}$ cos. l; therefore, C = $\frac{d\,\text{H}}{d\,l}$ = cot. A ÷ cos. l = cot. A sec. l, and C of the tables is revealed.

In Fig. 2, let S, s, be true and erroneous positions of sun; a, the altitude. With centre Z, radius s Z, describe arc s r. Then S r = error in altitude = $d\,a$. With centre P, radius PS or Ps, describe arc Ss. Then SPs = error in hour-angle = d H. The small triangle S r s is practically plane; and, therefore, Sr = Ss cos. sSr = Ss sin. PSZ...(IV.), because sSr + PSZ = PSs = 90°. But, by parallel sailing, Ss = SPs cos. δ = SPs sin. PS = d H sin. PS

Therefore, substituting this value of Ss, in (IV.), we get da = Sr = dH sin. PS sin PSZ...(V.). But sin. PS sin. PSZ = sin. PZ sin. PZS, because the sines of the angles of a spherical triangle are proportional to the sines of the opposite sides. Hence, substituting in (V.), we have $da = d$H sin. PZ sin. PZS = dH cos. l sin. A. Therefore dH = da sec. l cosec. A; and tabular D is obtained.

A merely nodding acquaintance with the differential calculus gives A, B, C, D, even easier. By usual formula, connecting the cosine of an angle with the sines and cosines of the sides of a spherical triangle, we have—

$$\sin. a = \sin. \delta \sin. l + \cos. \delta \cos. l \cos. H \;..(1)$$

Differentiating with respect to l and H, while a and δ are constant, O = sin. δ cos. $l\,dl$ - cos. δ sin. l cos. H dl - cos. δ cos. l sin H dH.

$$\therefore \frac{dH}{dl} = \frac{\sin. \delta \cos. l - \cos. \delta \sin. l \cos. H}{\cos. \delta \cos. l \sin. H} \;...(2)$$

$$= \tan. \delta \operatorname{cosec}. H - \tan. l \cot. H.$$

Assume $dl = 1$; then—

$$dH = \tan. \delta \operatorname{cosec}. H - \tan. l \cot. H$$
$$= -(\tan. l \cot. H - \tan. \delta \operatorname{cosec}. H)$$
$$= -(\text{tabular A} - \text{tabular B}).$$

Again differentiating (1), as above, we may write (2) as follows:—

$$\frac{dH}{dl} = \frac{\cos. a \cos. A}{\cos. \delta \cos. l \sin. H} = -\frac{\cos. a \cos. A}{\cos. a \cos. l \sin A}$$

$$\therefore C = -\cot. A \sec. l...(3)$$

Elementary trigonometry shows that cos. a sin. A = - cos. δ sin. H, also cos. a cos. A = sin. δ cos. l - cos. δ sin. l cos. H; and these values are substituted in (2).

Again, differentiating (1) with respect to a and H, with δ and l constant—

$$\text{Cos. } a\,da = -\cos. \delta \cos. l \sin. H\,dH$$

$$\therefore \frac{dH}{da} = -\frac{\cos. a}{\cos. \delta \cos. l \sin. H} \;...(4)$$

But, by ratio of sines of angles and opposite sides, - cos d sin H = cos. a sin. A. Hence, substituting this value in denominator of (4), we get—

$$\frac{dH}{da} = \frac{\cos. a}{\cos. l \cos. a \sin. A} = \frac{1}{\cos. l \sin. A} = \sec. l \operatorname{cosec}. A$$

Tabular D = sec. l cosec. A.

And we have now found the values of tabular A, B, C, and D.

* There is not anything inherently difficult in the solutions by trigonometry to anyone familiar with elementary navigation and nautical astronomy, and the calculus solutions are like playing knuckle-bones in the portal of the temple of mathematics. Let me strongly advise the student to thoroughly master the first six chapters of Todhunter's *Spherical Trigonometry* (Macmillan & Co.); also chapter XI. on small variations in the parts of a spherical triangle—a work to which I owe much.—W.A.

APPENDIX (R).

SUBSTITUTE FOR HORIZON.

Captain (now Rear-Admiral) B. A. Fiske, U.S. Navy, gave a method of finding the altitude of a celestial body by sextant from a vessel's deck when horizon is indeterminable. An angular altitude above some well-defined part of a ship, or other object, on the same vertical circle, situated at a known distance from the observer, is measured; and then the dip is found, for the measured altitude, by computing the angle subtended at the known distance by the difference in height between the observer's eye and the object angled on.

During the night of 2nd August, 1907, the warships *Arkansas*, *Florida*, and *Olympia*, being then in company, the suggested method was put to the test of experiment by Comm. Yates Stirling, U.S.N., of the *Arkansas*, Capt. B. A. Fiske, U.S.N. Sixteen hours previously the ships had been steaming in a dense fog, bound to Seguin Island from Block Island. About 10 h. 35 min. P.M., a clear enabled the *Arkansas* to make out distinctly the lights of her consorts. The sky was cloudless overhead, and many stars were visible, but the horizon was unavailable. Commander Stirling pressed Polaris into the service. A midshipman took the distances of the two ships by stadimeter; another noted the times; and the *Arkansas* was manœuvred so as to bring the stern lights of the *Florida* and of the *Olympia* directly under the star in succession. When by stadimeter the lights were distant 500 yards and 1000 yards respectively, altitudes of Polaris were taken by Commander Stirling. The actual computation of the sight on the *Olympia* is given below; and that for the sight on the *Florida* is the same, except that the dip was 29′ 48″ instead of 17′ 46″. The latitude found was 42° 46′ 9″ N., using the *Olympia;* and 42° 43′ N., using the *Florida*. Tan. dip = height ÷ distance.

Height 25·5	1·19033			
Dist. 3000	3·47712			
Dip 17′ 46″ tan	7·71321			
	H.	M.	S.	
G.M.T.	15	31	59 (Aug. 2)	
Sun's R.A.	8	39	43	
Corrn.	+	2	33	
G.S.T.	24	14	15	
Long.	4	38	20	
L.S.T.	19	35	55	
Star's R.A.	1	26	10	
Star's H.A.	18	9	45	
or (−)	87	33	45	cos 8·62870
p	71·6″			log 1·85491
Φ	3′ 3″			log 0·48361

Star's dec.	88°	48′	23″
p	71·6″		
	H.	M.	S.
Star's R.A.	1	26	10
Star's Alt.	43	8	0
Dip	−	17	46
Ref.	−	1	2
Corr.	−	18	48
h	42	49	12
Φ	−	3	3
L	42	46	9

At 1 h. 30 m. A.M. a sounding of 31 fathoms was obtained on Platt's Bank, thus fixing the position of the *Arkansas* within a mile. Working back from this it was found that the latitude at the time of sight of Polaris was 42° 45′ 30″ N.

During the forenoon of the ensuing day, while the *Arkansas* was anchored off Kennebec River, in a dense fog, Captain Fiske had a boat sent out in the sun's direction, near noon, to serve as an origin for latitude by sun, which shone brightly overhead although the dense fog precluded the boat from being made out beyond a distance of 173 yards. The resulting altitudes of the sun—one by a lieutenant, one by a midshipman—only differed 1′; and the resulting latitudes were 43° 6′ N. and 43° 7′ N. After the fog had fallen off, the latitude of the *Arkansas*, as determined by observations of Seguin Island, proved to be 4′ 15″ less than the mean of the two results obtained during the fog. Assuming an error in the adopted distance of the mark-boat from the observers, and a consequent error in the dip or angular depression of that part of the boat serving as the origin of altitudes, some observations were made for longitude from the *Arkansas* while at anchor off Bath, Maine, on 5th August. The sights, worked out singly, gave longitudes of 69° 53′ W., 69° 46′ W., 69° 51′ W., and 69° 47′ W. Meaning the four gives 69° 49′ W., and the correct result by chart was 69° 45′ 36″ W.

This method's reliability depends largely upon accuracy of dip applied to the angular altitude; and, therefore, upon the accuracy of measurement of the observer's distance from the mark-boat, or substituted object, and his height above it. Nevertheless the method is within the range of the practical navigator's requirements—failing others.

Let da, dx, be errors in altitude (a) and distance (x), respectively, then the effect in seconds of arc upon the deduced value of the dip is obtainable from the following equation:—

$$\frac{x \, . \, da - a \, . \, dx}{\sin 1'' \, (x^2 + a^2)}$$

Assuming that the observations of 3rd August were taken with eye five yards above the mark-level, then, if the estimated distance of 173 yards be 3 yards in error, the resulting dip will be out to the amount of 1′ 43″. In the example of 2nd August, if the given distance of 3000 feet be 30 feet in error, then the dip will be only 11″ out, provided the height was correct; and if, at the same time, there were an error of 3 inches in the height, then the resulting dip cannot be more than 28″ in error.

APPENDIX (S).

GYROSCOPIC COMPASSES.

The irresistible influence of modern methods in practical navigation demands that an elementary explanation shall be brought to the notice of the world's navigators with respect to that comparatively new aid to safe navigation known as the gyroscopic compass. A gyroscope is essentially a rotating wheel. Nevertheless it must not be illogically assumed that every rotating wheel is a gyroscope. A spinning top, or a rolling hoop, both dear to boys before going to sea, is the first left-handed introduction to a gyroscope; albeit this view of the matter fortunately does not enter into their school curriculum. Few riders of bicycles would give, offhand, the correct explanation of the curious circumstance that their trusty steeds succeed in keeping upright. Such knowledge, however, is not the basis of a cyclist's success as a prize-winner. It is proverbial that the philosopher who steered by the stars, doubtless assisted thereto by a critical command of the higher mathematics, eventually fell into a lowly but open well. A bicycle is merely one form of a rolling hoop! A gyroscopic compass is costly, delicate, and elaborate. Hence we may fairly compare it, in some ways, with a bicycle of repute. At a fair speed a boy's hoop will run straight; but when its onward motion decreases, as young trundlers are well aware, such a pleasant plaything commences to wobble and eventually comes to the ground. Every rotating wheel displays a tendency to set its own axis parallel to that about which it happens to be rotating. Hence, inasmuch as the axis, about which everything in this connection is rotating is that of our planet, it follows that a spinning wheel, fixed in a frame free to move in any direction, will eventually assume a position so that the respective ends of its axis point north and south. A wheel gyroscope of this nature governs not only the uprightness of a spinning top, so dear to many a generation, but also the earth on its axis. Such a wheel, rotating rapidly, affords an example of Newton's three laws of motion, that may be enunciated as follow: 1. Every body continues in a state of rest, or of uniform motion in a straight line, except in so far as it may be compelled to change that state by force acting upon it. (2) Change of motion is proportional to the acting force, and takes place in the direction of the straight line in which the force acts. (3) To every action there is always an equal and corresponding reaction; or the mutual relations of any two bodies are always equally and oppositely directed in the same straight line. When those laws are applied to rotating bodies we get, respectively, the phenomena of gyroscopical inertia, precession, and the mathematical relation of precession to external force. Applications of the gyroscope depend, more especially, upon the two first.

Gyroscopic inertia is that property by virtue of which a well-balanced gyroscope will maintain the direction of its axle stationary when set parallel to the axis of the earth. Unless the gyro-wheel axle be parallel to the earth's axis it will appear to rotate against the hands of a watch, about a line parallel to the earth's axis, looking from South to North, with a sidereal day period of 23 h. 56 min. 4 secs. A perfectly balanced gyroscope is not suitable for navigational purposes, as it would never come to rest under the prevailing conditions.

Precession is the motion due to an attempt to rotate the plane of rotation of a spinning wheel. The applied force meets with much resistance; and the direction of rotation of the wheel's plane is at right angles to the plane of the force causing it, and in a direction that places the direction of the wheel's rotation like that of the force, if the wheel is free to turn in any direction. This opposing force is caused by the precession, which varies inversely as the weight, speed, and the square of the diameter of the wheel. Hence the advantage of a wheel of considerable diameter. A balanced gyro will precess in one direction about a vertical axis, provided a suitable weight be hung in line with the end of its axis. Consequent on inertia, rotation of the earth, and precession, an approximately twenty-four hour circular track is connected with an ellipse of much shorter period having a comparatively long and horizontal major axis. The "simple oscillation" across a meridian is common to all kinds of gyro-compasses. Further steps are taken to ensure that the gyro axis will come to rest in the centre of oscillation; and numerous arrangements have been devised to effect this result and thus arrive in the shortest possible way of a reliable compass. Further information may be gleaned in detail from an article by A. E. Gott, A.M.I.E.E., which appeared in the *Nautical Magazine* of September, 1916. Even the easiest of explanations, it must be admitted, is somewhat difficult to follow.

Foucault, an eminent French philosopher, so long ago as 1852, arrived at the sound conclusion that a gyroscope evinces a tendency to seek the true North. Yet only in comparatively recent times has this pregnant property been taken advantage of for service conditions on board ships at sea. To-day, however, a large number of the world's warships and large liners are fitted with gyroscopic compasses of precision. The theory that a heavy and rapidly spinning disc, supported at its centre of gravity, will retain its direction in space was probably dimly realized prior to the convincing investigations of Foucault. In a tentative way, however, that learned Frenchman preferred to regard the principle as an experimental demonstration of the earth's rotation on its axis. Subsequently he explained that if such a gyroscopic disc were mounted so as to ensure that the axis on which it turned could not be moved with complete freedom, but solely about a vertical axis, the resulting position in which the axis would be at rest must be due North and South. This is the fundamental principle determining the utility of a gyroscopic compass for the practical purposes of the navigator. Not till an electric motor had become an accomplished fact, as Foucault might have said in his own tongue, was it possible to rotate the disc at a speed sufficient for the purpose in view. A gyroscopic compass, from one vantage ground, may be roughly regarded as a liquid compass in which the magnetic needle is replaced by a rotating gyro having its axis always pointing true North and South. This is what is required by navigators in ships of iron or of steel in order to ensure a maximum of safety.

A gyroscopic compass has several highly attractive advantages, over the usual magnetic compass, that tend to commend the former to seafarers on board ships where time is more especially synonymous with money. Consequently this type of aid to safe and speedy navigation is coming more and more frequently under the close consideration of the most important shipping industries of the principal maritime nations. A gyroscopic compass, however, is not only delicate but also characteristically complicated. Moreover, owing to the employment of various attachments that are unavoidably elaborate in some instances, a gyroscopic compass is comparatively costly to buy and to maintain. Nevertheless, it indicates the true North without much trouble; and this is a property not lightly to be despised, or ignored, in these trying times of quick passages under all sorts of meteorological conditions. The principal merit of a gyroscopic compass is dependent upon the fact that its indications are unaffected by the earth's magnetism; albeit the gyroscopic compass must be credited with a directive force, similar to, but many times greater than, that of a magnetic compass. At any place on the earth's surface, other than those poles where none but enthusiasts are likely to venture, a gyroscope, provided it is free to move only in the planes, will evince a tendency to set itself with axis of rotation parallel to the earth's axis consequent on the relative rotations of the two bodies. The respective ends of the gyro-wheel are termed "north-seeking" or "south-seeking" according to the direction of spin. Variation charts, deviation tables, correcting magnets and correcting spheres, troubles due a ship's pitching and rolling in a heavy seaway, and similar items pertaining to the magnetic compass that was alone available to the old-timer, all vanish below the horizon of progress when a gyro-compass is in use, as though compelled by the weird influence of a magician's wand. Any kind of metal may remain in close proximity to a gyro-compass without turning its head. Even the old sailors' yarns as to the adverse influence of the steel hoops in a lady passenger's crinoline of the olden time, and the steel in the cork leg of a pilot on the Great Lakes of North America, will be without point where a gyroscopic compass is regarded as *facile princeps.* Fair weather, or foul; blow high, or blow low; thick weather or cloudless sky; any navigator, using a gyro-compass intelligently, has always at command the bearing of true North without either sights or calculation. Three hours previous to proceeding on a passage, or at the instant when word is passed along to get up steam, a similar action can be arranged for the gyro-compass should it be temporarily out of commission. If deemed desirable by the shipmaster concerned, this kind of compass can be kept in action continuously, inasmuch as the wear on its bearings is relatively a negligible quantity. The gyro-compass cannot rightly be expected to universally supersede the navigator's familiar friend of long-standing known as the magnetic compass; but the latter type seems destined in the near future, to become a stand-by, on many a warship and large liner under every flag, on all fours with the hand-steering gear of such a ship that is seldom brought into play except when a break-down occurs with the modern apparatus.

Foucault's theory involves the proposition that "every free rotating body, when subjected to some other or new turning force, tends to set its axis of rotation parallel to the new axis of rotation by the shortest path, so that the two rotations take place in the same direction." This, concisely stated, is the main principle upon which is based the working of a gyro-compass as a reliable assistant to navigators "bound to go." The late Lord Kelvin, ever eager to lessen risks for the world's navies, whether of peace or of war, by translating abstract mathematics, that are understood but by the few, into concrete contrivances that are infinitely useful for the multitude, devoted much of his invaluable time, and his unsurpassed genius, to the betterment of the gyroscope under various heads. To him, greatly, we owe the fact that it cast off its limited environment of initial usefulness as a toy for natural-philosophy classes at the Universities and elsewhere. The United Kingdom, the United States, and other maritime countries that count, have constructed gyroscopic compasses on lines first satisfactorily laid down by Kelvin in one of his many and varied contributions to practical mathematics. Inventive capacity and "high science" are not necessarily co-existent in an individual; but the late Lord Kelvin, himself a navigator, was a brilliant exception to a general rule as sailors are well aware and freely admit. Mathematical machines neither invent nor discover. Kelvin was both an inventor and a discoverer; and Kelvin was a mathematician with a bent for the sea. Such a combination of theory and practice is rare.

A gyro-compass is similar in external appearance to the magnetic compass it is likely to supplant on board vessels where initial expenditure is a secondary consideration when attempting to solve the problem of increased safety of life at sea. The card of this class of compass, as is now the case with some of the old-fashioned type, is marked from 1° to 360°. In a few there is an auxiliary card, arranged in the centre of the dial, that makes a complete revolution for a small change in course; and is divided so that an alteration in ship's head, if only of a few minutes of arc, is immediately apparent. The weighty disc is rotated by a small motor, and mounted in a framework that floats on mercury; the whole instrument being balanced so that the tendency of the flotation shall ensure the disc being vertical and its axis being horizontal. It is this tendency, according to Foucault's principle, that compels the axis to point North and South. Two strings to a bow are proverbially good! Hence the following method of regarding this matter may prove useful. If the gyro-wheel were caused to rotate with its plane vertical, and in the meridian of the observer, then the rotation will maintain it in a fixed direction in space; but as the earth itself is turning, this tends to incline the plane of the gyro-wheel to the meridian. On the other side we have the floating power of the mercury tending to upright the disc, or gyro-wheel. The resultant of these two tendencies is to compel the disc into that only position of stability when it is vertical and square to the meridian. In other words, the axis about which the disc then rotates will point due North and South.

When it is required to lay off a course with the aid of a gyro-compass solely, two corrections may have to be regarded by navigators concerned in that operation. Both will, perhaps rightly, be regarded as negligible for the practical purposes of navigation where give and take is an order of the day. Tables are supplied, however, for the purpose of allowing for those tiny and tedious items should such a course of procedure be deemed desirable by those intimately concerned. One of those corrections depends upon an adverse influence introduced by change of latitude, should such take place. A vessel, for example, leaving a United Kingdom port, would have her gyro-compass carefully adjusted to the parallel of 50°. Unless she change her latitude as much as 10°, this adjustment will serve every purpose. Going north, or south, across the equator, for example, a navigator can, if he feel desirous of doing so, quite readily adjust his gyro-compass, for latitude-error, by following the rules laid down for his guidance in an accompanying book of instructions. Such an operation need be carried out only crossing each tenth parallel of latitude. Another correction, known as the δ correction, is merely the expression of the geometrical relation between the speed of the ship and the speed of the earth's rotation. A reference to the tables that are supplied with a gyro-compass, as above mentioned, suffices to master this correction should it be deemed essential in practical navigation.

There are three prominent types of gyro-compasses, known as the "Anschutz," the "Sperry," and the "Sea Star," respectively. Preliminary experiments appear to have been carried to a successful finish, about 1900, by Mr. Elphinstone with the Anschutz type, for the purpose of determining a substitute for the usual magnetic compass on board a ship about to set out for the Arction regions on a North Polar Expedition. Eleven years later, Mr. Elphinstone made a detailed statement in a paper read before a meeting of that year's British Association, during the course of which he described the many methods he had availed himself of in order to conquer the apparently inherent defects of such a system, and also the success that crowned his unsparing efforts. This type of gyroscopic compass is of pendular construction, free to swing under the action of gravity. Three gyro-wheels counteract any adverse effect likely to be introduced by violent behaviour, in a heavy sea, of the ship on which the gyro-compass is fitted. Their peripheral speed is said to be between 20,000 and 30,000 revolutions a minute. Special motor generators had to be employed having a periodicity of 330 per second. Attached spirit-levels indicate whether the instrument is properly performing its allotted duty in pointing out the true North to the anxious mariner. A "Sperry" gyro-compass is suspended by a wire that is kept mechanically deprived of twist directly the gyro-wheel is in motion; and the latter is destitute of friction round the vertical axis. The gyro-wheel revolutions are 8600 a minute, and the periodicity is 145 per second. In this type of gyro-compass a "follow-up" motor leaves the gyro-wheel with but little work to do. Errors in compasses of this nature are due to latitude, change of latitude at constant speed, change of speed, pitching and rolling of the ship viewed as a compass platform, slowness of the gyroscope, and the quality of the steering of the ship. All these elements of discordance and doubt are traceable to the fact that such compasses are pendular and rely upon the action of gravity. The "Sea Star" type, designed by Captain V. H. Rozic and Mr. E. Kilburn Scott, has a clockwise direction of rotation of the gyro-wheel when looking at the north-seeking end of the gyro-wheel spindle. In the two first-mentioned types, the direction of rotation of the gyro-wheel is against the hands of a watch held face upwards-counter-clockwise. Consequent on the gyro-wheel rotation in the "Sea Star" type being opposite to that of the earth, the gyro-wheel in this instance is in unstable equilibrium. Hence the motor, in this compass, is said to correct any tendency to deflection. There is thus induced a general sensitiveness that permits of the adoption of comparatively small instruments, inasmuch as the kinetic energy of the wheel is not so important as it is with other forms of compasses.

A master-compass, or, as it is sometimes termed, a mother-compass, may be regarded as the standard compass of the gyro-class. It may be placed in position either down below, or on the uppermost deck or bridge; but, in every instance, this kind of compass should be directly on the centre-line of the ship concerned. A master-compass may be used directly as the steering compass; or it can be used for controlling other gyro-compasses, situated in various positions on the same ship, that are fitted so as to receive its indications by means of a special transmitter.

Radio-telegraphy as it becomes more and more common will be pressed into various services for the guidance of ships in the vicinity of the land. Signals from another ship, from a light-ship, or from a lighthouse, can be utilized. The Marconi-Bellini Tosi wireless direction-finder enables a navigator to determine, very nearly, the bearing of a radio-station whence a message is received. It is said that the range of communication lies between the limits of ten miles and fifty miles or more, varying with the power of the sending station. Probably the first reliable records on this plan were made from the S.S. *Royal George,* between Canada and England. She got the bearings of Cape Race, Cape Ray, and Father Point, with certainty and despatch, as also of vessels under way. Another steamer, the *Esquimo,* bound from Hull to Christiania, enjoyed a like experience. The aerial waves are quite distinct from the ordinary wireless installation on board signalling ships. It would appear that at the date of writing, October, 1916, this method merely allows of the determination of a line of bearing somewhere on which the ship happens to be. The United States Navy authorities have called the attention of shipmasters whose vessels are fitted with radio-telegraphy apparatus, that are in the vicinity of Cape Cod, to the fact that a "Distance Finder" had just been installed at the United States Navy Radio Station, North Truro, Mass.; and it was suggested that those immediately interested should put the utility of the proposed method to the test of experience. Albeit in its tentative stage, this system is said to have afforded results differing only by a couple of degrees from the corresponding bearings obtained by recourse to the compass as of old. Apparently this method furnishes an observer with an indication as to the line on which the sending station is at the instant of observation. Thus a bearing of 20° on the starboard bow, for example, is not distinguishable from one that is 20° on the port quarter. Seldom, however, does doubt arise under this head. Two successive readings of a course that is maintained during the interval will place the matter on the bed-rock of certainty, and at the same time give the listening ship's distance from the sending station in the usual way. Should two coast-stations be within wireless touch, a ready reference to the ship's geographic position is placed on record. A wireless compass not only enables a vessel to locate her geographical position, but also the position of an approaching vessel fitted with radio-telegraphy apparatus. Navigators familiar with mathematical formulæ of more than Kindergarten complexity will find Chapter XVII. of Glazebrook and Shaw's *Practical Physics* of the highest importance in connection with magnetism and ship's compasses. It is to be hoped that in the next edition they will fully explain both the gyro-compass and the radio-compass.

APPENDIX (T).

THE MOON AN AUXILIARY.

The moon occasionally helps a navigator; but is generally left severely alone, consequent on the many vexatious corrections that she generally demands. A correspondent of the *Nautical Magazine* quite recently quoted an instance where Luna was an aid to safe navigation. Bound from Port Arthur, Texas, to London, and expecting to be in the vicinity of the Tortugas in the early morning, the master was anxious to obtain a sight—hitherto impossible on the passage. Concluding that a clear was probable, he waited with sextant in hand, and the mate standing by at the chronometer. Suddenly the Moon became visible on the port bow, and Sirius followed suit to starboard. The whole operation, the sights being carried out in quick succession, lasted only a minute and a half; and no other sight was possible that night. A table due to Messrs. A. McLellan and S. P. Elliott, given in Brown's *Nautical Almanac*, affords the necessary correction of the moon's altitude at sea by the use of a single term. Having given, for example: Moon's altitude 45° 18′ 10″, hor. par. 55′ 37,″ height of eye 16 feet, we get by Brown's Table—

	°	′	″
Alt. . . .	45	18	10
Corr. . . .	+	19	6
	45	37	16

	From Table.
Alt. 45° / Hor. par. 55·5′ } . .	14·7′
Add for 16 ft. height . .	4·4
	19·1
	19′ 0″

APPENDIX (U).

CHRONOMETERS: USE AND ABUSE.

In the exhibit of the United States Navy at the Panama-Pacific Exposition there were some chronometers having marvellous histories. One, found by the Nares' Arctic Expedition in Newman's Bay, had been abandoned in the American discovery ship *Polaris*, 1872, nearly four years prior to its recovery. Presented to the United States Government after the return home of Nares and his gallant crew, it is still running with marked accuracy. Another, equally satisfactory, was in use during an Arctic expedition of 1850. The first chronometer of American make used by the United States authorities was similarly in active service. Two chronometers that went to the bottom with the United States warship *Maine* during Feb. 1898, in Havana harbour, and remained submerged for fourteen years, were also on exhibition, albeit rusted almost beyond recognition. An "ardent disciple" of *Wrinkles*, in a letter published not long since in the *Nautical Magazine*, pointed out in detail that the chronometers of a large line were kept in improperly-constructed receptacles, no chronometer journal kept, and no daily comparisons taken. The shop-rate was invariably relied upon and unhesitatingly used. Having carefully plotted the ship's position by cross bearings of well-defined points on shore, and then determined the longitude by each of two chronometers in the usual way, it was found that one placed the ship nine minutes of longitude, and the other seventeen minutes of longitude, away from her actual spot. The three chronometers carried on ships of that line were sent ashore at either end of the route and remained until the eve of sailing. "Even when every precaution is taken," wrote James Page, on a Pilot Chart of the United States Hydrographic Office, Washington, D.C., in 1902, "it is impossible to carry" a chronometer "from place to place without altering its rate . . . It frequently happens that the sea or travelling rate is quite distinct from the land rate, owing to the change of surroundings." To delay the arrival of a chronometer on board until the day of sailing is seldom justifiable, and sometimes dangerous.

EXTRACTS FROM NAUTICAL ALMANACS

FOR VARIOUS YEARS,

WHICH HAVE REFERENCE TO THE EXAMPLES

GIVEN IN THE BODY OF THIS BOOK.

AT MEAN NOON.

Day of the Week.	Day of the Month.	THE SUN'S Apparent Declination.	THE SUN'S Var. in 1 Hour.	Equation of Time, *to be subtracted from Mean Time.*	Var. in 1 Hour.	Sidereal Time.
		° ′ ″	″	m s	s	h m s
Sat.	14	14 25 49·4	46·19	4 30·93	0·460	9 30 0·27
Sun.	15	14 7 14·1	46·75	4 19·63	0·483	9 33 56·83
Mon.	16	13 48 25·3	47·30	4 7·78	0·505	9 37 53·38

AT UPPER TRANSIT AT GREENWICH.

Month and Day.	α Virginis. (*Spica*). R.A.	α Virginis. (*Spica*). Dec. *South.*	α Piscis Australis. (*Fomalhaut*). R.A.	α Piscis Australis. (*Fomalhaut*). Dec. *South.*	
	h m 13 18	° ′ 10 30	h m 22 50	° ′ 30 16	
	s	″	s	″	
Jan. 1	35·84	28·0	43·49	79·1	
11	36·19	30·1	43·41	78·6	
21	36·52	32·2	43·35	77·9	
31	36·84	34·2	43·32	76·9	
Feb. 10	37·14	36·1	43·32	75·7	
20	37·40	37·9	43·35	74·2	
Mar. 2	37·63	39·4	43·43	72·3	
12	37·83	40·7	43·53	70·4	
22	37·99	41·8	43·67	68·4	
April 1	38·11	42·7	43·86	66·2	
11	38·20	43·4	44·08	63·9	
21	38·26	43·8	44·33	61·6	
June 10	38·20	43·7	46·00	50·9	
20	38·13	43·4	46·36	49·3	
30	38·05	43·0	46·71	48·0	
July 10	37·96	42·5	47·05	47·0	
20	37·86	41·9	47·36	46·4	
30	37·75	41·3	47·63	46·1	
Aug. 9	37·65	40·8	47·86	46·1	
19	37·55	40·2	48·04	46·5	
29	37·46	39·7	48·17	47·2	

II. JANUARY, 1880.

Day of the Week.	Day of the Month.	THE SUN'S *Apparent* Declination.	THE SUN'S Var. in 1 hour.	Equation of Time, *to be subtracted from Mean Time.*	Var. in 1 hour.	Sidereal Time.
AT MEAN NOON.						
		° ′ ″	″	m s	s	h m s
Thur.	15	S. 21 11 6·0	27·35	9 33·02	0·893	19 37 18·37
Frid	16	20 59 57·6	28·36	9 54·09	0·863	19 41 14·93
Sat.	17	20 48 25·3	29·36	10 14·45	0·833	19 45 11·48
Sun.	18	20 36 29·2	30·34	10 34·09	0·803	19 49 8·04
FEBRUARY, 1880.						
Frid.	20	S. 11 1 37·9	53·72	14 0·54	0·266	21 59 14·38
Sat.	21	10 40 3·5	54·13	13 53·82	0·294	22 3 10·93
Sun.	22	10 18 19·4	54·53	13 46·44	0·321	22 7 7·48
MARCH, 1880.						
Sat.	6	S. 5 23 49·8	58·27	11 18·95	0·600	22 58 22·68
Sun.	7	5 0 28·9	58·45	11 4·37	0·615	23 2 19·23
Mon.	8	4 37 3·9	58·61	10 49·42	0·630	23 6 15·79

MAY, 1880.

Day of the Week.	Day of the Month.	THE SUNS *Apparent* Declination.	THE SUNS Var. in 1 hour.	Equation of Time, *to be added to Mean Time.*	Var. in 1 hour.	Sidereal Time.
AT MEAN NOON.						
		° ′ ″	″	m s	s	h m s
Tues.	18	N. 19 41 57·7	32·44	3 44·80	0·099	3 46 11·13
Wed.	19	19 54 46·1	31·59	3 42·16	0·121	3 50 7·69
Thur.	20	20 7 14·1	30·74	3 38·99	0·143	3 54 4·24

II. JUNE, 1880. 93

AT MEAN NOON.

Day of the Week.	Day of the Month.	THE SUN'S Apparent Declination.			THE SUN'S Var. in 1 hour.	Equation of Time, to be added to / subt. from Mean Time.		Var. in 1 hour.	Sidereal Time.		
		°	′	″	″	m	s	s	h	m	s
Frid.	4	N. 22	30	59·9	16·86	1	52·41	0·431	4	53	12·60
Sat.	5	22	37	32·7	15·87	1	41·88	0·446	4	57	9·16
Sun.	6	22	43	41·7	14·88	1	31·02	0·459	5	1	5·72
Mon.	7	22	49	26·8	13·88	1	19·85	0·471	5	5	2·28
Tues.	8	22	54	47·9	12·88	1	8·40	0·483	5	8	58·83
Wed.	9	22	59	44·8	11·87	0	56·69	0·493	5	12	55·39
Frid.	18	23	25	55·8	2·65	0	56·10	0·538	5	48	24·41
Sat.	19	23	26	47·0	1·62	1	9·02	0·538	5	52	20·97
Sun.	20	23	27	13·4	0·58	1	21·93	0·537	5	56	17·53
Mon.	21	23	27	15·1	0·45	1	34·82	0·536	6	0	14·09
Tues.	22	23	26	52·0	1·48	1	47·67	0·534	6	4	10·65
Wed.	23	23	26	4·2	2·51	2	0·46	0·531	6	8	7·20
Thurs.	24	23	24	51·7	3·54	2	13·16	0·527	6	12	3·76
Frid.	25	23	23	14·4	4·57	2	25·76	0·523	6	16	0·32
Sat.	26	23	21	12·5	5·60	2	38·25	0·517	6	19	56·88

JULY, 1880.

Day of the Week.	Day of the Month.	Apparent Declination.			Var. in 1 hour.	Equation of Time.		Var. in 1 hour.	Sidereal Time.		
Tues.	6	N. 22	38	30·8	15·68	4	31·97	0·414	6	59	22·46
Wed.	7	22	32	2·8	16·66	4	41·73	0·399	7	3	19·01
Thur.	8	22	25	11·4	17·63	4	51·11	0·382	7	7	15·57

SEPTEMBER, 1880. 147

AT MEAN NOON.

Day of the Week.	Day of the Month.	THE SUN'S Apparent Declination.			THE SUN'S Var. in 1 hour.	Equation of Time, to be added to Mean Time.		Var. in 1 hour.	Sidereal Time.		
		°	′	″	″	m	s	s	h	m	s
Tues.	14	N. 3	10	10·9	57·72	4	41·13	0·883	11	35	21·32
Wed.	15	2	47	3·5	57·86	5	2·35	0·885	11	39	17·88
Thurs.	16	2	23	52·9	57·99	5	23·61	0·886	11	43	14·43
Wed.	22	N. 0	4	0·8	58·46	7	30·62	0·871	12	6	53·75
Thur.	23	S. 0	19	23·1	58·50	7	51·46	0·865	12	10	50·30
Frid.	24	0	42	47·7	58·51	8	12·15	0·858	12	14	46·85
Sat.	25	1	6	12·5	58·52	8	32·67	0·850	12	18	43·41

DECEMBER, 1880.

AT MEAN NOON.						
Day of the Week.	Day of the Month.	THE SUN'S Apparent Declination.	THE SUN'S Var. in 1 hour.	Equation of Time, *to be added to Mean Time.*	Var. in 1 hour.	Sidereal Time.
		° ′ ″	″	m. s.	s.	h. m. s.
Frid.	17	S. 23 23 37·9	4·63	3 23·84	1·229	17 45 57·50
Sat.	18	23 25 14·9	3·45	2 54·26	1·236	17 49 54·06
Sun.	19	23 26 23·6	2·28	2 24·55	1·240	17 53 50·61

JANUARY, 1880.

MEAN TIME.

THE MOON'S

Hour.	Right Ascension.	Var. in 10m.	Declination.	Var. in 10m.
	SATURDAY, 17.			
	h m s	s	° ′ ″	″
0	0 16 33·25	19·150	N. 7 29 2·0	128·56
1	0 18 28·14	19·148	7 41 52·0	128·10
2	0 20 23·02	19·146	7 54 39·2	127·63
3	0 22 17·89	19·145	8 7 23·6	127·16
4	0 24 12·76	19·145	8 20 5·1	126·68
5	0 26 7·63	19·145	8 32 43·7	126·19
6	0 28 2·50	19·145	8 45 19·4	125·71
7	0 29 57·37	19·147	8 57 52·2	125·21
8	0 31 52·26	19·149	9 10 21·9	124 70
9	0 33 47·16	19·152	9 22 48·6	124·19
10	0 35 42·08	19·155	9 35 12·2	123·67
11	0 37 37·02	19·159	9 47 32 6	123·14
12	0 39 31·99	19·164	9 59 49·9	122·62
13	0 41 26·99	19·168	10 12 4·0	122·08
14	0 43 22·01	19·174	10 24 14·8	121·53
15	0 45 17·08	19·181	10 36 22·4	120·98
16	0 47 12·18	19·188	10 48 26·6	120·42
17	0 49 7·33	19·195	11 0 27·4	119·86
18	0 51 2·52	19·203	11 12 24·9	119·29
19	0 52 57·76	19·212	11 24 18·9	118·72
20	0 54 53·06	19·221	11 36 9·5	118·13
21	0 56 48·41	19·230	11 47 56·5	117·54
22	0 58 43·82	19·240	11 59 40·0	116·95
23	1 0 39·29	19·251	N. 12 11 19·9	116·34

332 APPARENT PLACES OF STARS, 1880.

AT UPPER TRANSIT AT GREENWICH.

Month and Day.		α Andromedæ. R.A.	α Andromedæ. Dec. N.	α Aurigæ. (*Capella*) R.A.	α Aurigæ. (*Capella*) Dec. N.	α Canis Majoris. (*Sirius*) R.A.	α Canis Majoris. (*Sirius*) Dec. S.	α Leonis. (*Regulus*) R.A.	α Leonis. (*Regulus*) Dec. N.
		h m	° ′	h m	°	h m	° ′	h m	° ′
		0 2	28 25	5 7	45 52	6 39	16 33	10 2	12 32
		s	″	s	″	s	″	s	″
Jan.	1	11·88	55·3	52·81	34·0	53·90	10·3	0·81	61·1
	11	11·75	54·4	52·81	35·3	53·97	12·7	1·08	59·7
	21	11·62	53·2	52·74	36·5	53·98	14·9	1·31	58·5
	31	11·51	51·8	52·62	37·4	53·95	16·9	1·50	57·6
Feb.	10	11·42	52·2	53·45	38·1	53·87	18·6	1·63	57·0
	20	11·35	48·6	52·24	38·5	53·75	20·0	1·72	56·6
Mar.	1	11·32	47·0	52·00	38·7	53·60	21·2	1·76	56·4
	11	11·32	45·4	51·75	38·5	53·42	22·0	1·75	56·5
	21	11·37	44·0	51·50	38·0	53·24	22·5	1·70	56·7
	31	11·46	42·8	51·27	37·2	53·05	22·6	1·62	57·1
Apr.	10	11·60	42·0	51·08	36·2	52·86	22·4	1·52	57·6
	20	11·79	41·5	50·92	35·0	52·69	21·9	1·40	58·1
	30	12·02	41·4	50·81	33·7	52·54	21·2	1·28	58·7
May	10	12·28	41·7	50·76	32·3	52·42	20·1	1·15	59·2
	20	12·58	42·4	50·78	30·8	52·34	18·8	1·03	59·7
	30	12·91	43·4	50·86	29·4	52·30	17·3	0·91	60·2
June	9	13·25	44·8	51·01	27·9	52·29	15·6	0·81	60·6
	19	13·60	46·6	51·20	26·6	52·33	13·7	0·73	61·0
	29	13·95	48·6	51·45	25·5	52·40	11·8	0·67	61·3
July	9	14·29	50·8	51·75	24·6	52·52	9·6	0·63	61·5
	19	14·61	53·2	52·08	23·9	53·66	7·6	0·61	61·6
	29	14·89	55·7	52·44	23·3	52·84	5·8	0·61	61·6
Aug.	8	15·16	58·2	52·83	23·0	53·05	4·1	0·64	61·4
	18	15·39	60·7	53·24	22·9	53·28	2·6	0·70	61·1
	28	15·57	63·2	53·65	22·9	53·53	1·5	0·79	60·6
Sept.	7	15·72	65·5	54·07	23·1	53·79	0·7	0·91	60·0
	17	15·82	67·7	54·49	23·6	54·07	0·3	1·05	59·2
	27	15·89	69·8	54·89	24·1	54·36	0·3	1·23	58·1
Oct.	7	15·91	71·6	55·29	24·8	54·65	0·8	1·44	56·8
	17	15·90	73·1	55·67	25·7	54·95	1·7	1·69	55·4
	27	15·86	74·4	56·03	26·7	55·24	3·1	1·96	53·8
Nov.	6	15·79	75·4	56·36	27·8	55·52	4·8	2·25	52·0
	16	15·70	76·2	56·65	29·0	55·78	6·9	2·47	50·1
	26	15·59	76·6	56·90	30·4	56·02	9·2	2·90	48·2
Dec.	6	15·47	76·7	57·10	31·7	56·24	11·6	3·23	46·3
	16	15·34	76·5	57·24	33·1	56·41	14·2	3·56	44·5
	26	15·20	75·9	57·33	34·5	56·54	16·8	3·87	42·8
	36	15·06	75·1	57·35	35·8	56·63	19·2	4·15	41·2

APPARENT PLACES OF STARS, 1880. 343

AT UPPER TRANSIT AT GREENWICH.

Month and Day.		α Ursæ Majoris.		α Virginis. (*Spica*)		η Ursæ Majoris.		α Bootis. (*Arcturus*)	
		R.A.	Dec. N.	R.A.	Dec. S.	R.A.	Dec. N.	R.A.	Dec. N.
		h m 10 56	° ′ 62 23	h m 13 18	° ′ 10 32	h m 13 42	° ′ 49 54	h m 14 10	° ′ 19 47
		s	″	s	″	s	″	s	″
Jan.	1	21·54	30·8	53·10	9·2	49·12	21·8	11·76	74·7
	11	22·07	31·1	53·44	11·2	49·55	19·9	12·09	72·4
	21	22·56	32·0	53·77	13·2	49·99	18·5	12·42	70·5
	31	22·97	33·3	54·08	15·2	50·41	17·8	12·74	68·9
Feb.	10	23·30	35·2	54·37	17·0	50·81	17·7	13·06	67·7
	20	23·53	37·4	54·63	18·7	51·18	18·2	13·35	67·0
Mar.	1	23·67	39·8	54·86	20·2	51·51	19·2	13·61	66·7
	11	23·71	42·4	55·05	21·4	51·78	20·8	13·84	66·9
	21	23·66	45·0	55·20	22·4	51·99	22·8	14·04	67·5
	31	23·53	47·5	55·32	23·2	52·15	25·1	14·20	68·4
Apr	10	23·33	49·9	55·41	23·8	52·25	27·7	14·32	69·5
	20	23·07	52·0	55·46	24·2	52·30	30·4	14·41	71·0
	30	22·76	53·7	55·49	24·4	52·29	33·1	14·47	72·6
May	10	22·43	55·0	55·49	24·4	52·24	35·7	14·50	74·2
	20	22·08	55·9	55·47	24·3	52·14	38·2	14·50	75·8
	30	21·72	56·4	55·43	24·1	52·00	40·5	14·47	77·4
June	9	21·38	56·3	55·37	23·7	51·83	42·4	14·42	78·9
	19	21·06	55·8	55·30	23·3	51·64	43·9	14·35	80·2
	29	20·77	54·7	55·21	22·8	51·42	45·0	14·26	81·4
July	9	20·51	53·2	55·11	22·2	51·19	45·7	14·14	82·3
	19	20·30	51·4	55·00	21·5	50·94	45·9	14·01	83·0
	29	20·13	49·2	54·89	20·9	50·69	45·7	13·87	83·4
Aug.	8	20·01	46·6	54·78	20·3	50·45	45·0	13·72	83·5
	18	19·96	43·8	54·67	19·6	50·22	43·9	13·58	83·4
	28	19·96	40·8	54·58	19·0	50·00	42·3	13·44	83·0
Sept.	7	20·03	37·2	54·50	18·5	49·80	40·3	13·31	82·2
	17	20·17	33·9	54·45	18·0	49·64	37·9	13·20	81·2
	27	20·37	30·5	54·43	17·7	49·53	35·3	13·11	79·9
Oct.	7	20·64	27·2	54·45	17·7	49·46	32·3	13·06	78·3
	17	20·98	24·0	54·52	17·9	49·44	29·0	13·06	76·4
	27	21·39	20·9	54·63	18·3	49·50	25·2	13·10	74·2
Nov.	6	21·85	18·1	54·79	19·0	49·62	21·7	13·19	71·6
	16	22·37	15·6	54·99	20·0	49·80	18·2	13·32	69·1
	26	22·92	13·6	55·24	21·3	50·04	14·7	13·51	66·4
Dec.	6	23·50	12·0	55·52	22·8	50·34	11·5	13·74	63·7
	16	24·09	10·9	55·83	24·5	50·70	8·5	14·01	61·1
	26	24·68	10·3	56·16	26·4	51·10	5·9	14·31	58·5
	36	25·23	10·3	56·49	28·3	51·52	3·7	14·63	56·1

AT UPPER TRANSIT AT GREENWICH.

Month and Day.		α Ophiuchi. R.A.	α Ophiuchi. Dec. N.	α Aquilæ. (*Altair*) R.A.	α Aquilæ. (*Altair*) Dec. N.	α Cygni. R.A.	α Cygni. Dec. N.
		h m 17 29	° ′ 12 38	h m 19 44	° ′ 8 33	h m 20 37	° ′ 44 50
		s	″	s	″	s	″
Jan.	1	21·42	49·5	55·33	9·3	19·36	76·3
	11	21·62	47·3	55·40	7·8	19·32	73·5
	21	21·85	45·3	55·52	6·2	19·32	70·7
	31	22·11	43·5	55·66	4·7	19·38	67·5
Feb.	10	22·38	41·9	55·83	3·4	19·49	64·6
	20	22·67	40·7	56·03	2·3	19·65	62·0
Mar.	1	22·97	39·9	56·26	1·5	19·85	59·7
	11	23·26	39·5	56·51	1·1	20·10	57·8
	21	23·56	39·5	56·77	1·0	20·39	56·4
	31	23·85	39·9	57·05	1·3	20·72	55·5
Apr.	10	24·12	40·7	57·34	1·9	21·07	55·2
	20	24·38	41·9	57·64	2·9	21·43	55·5
	30	24·62	43·3	57·94	4·3	21·81	56·4
May	10	24·84	45·0	58·24	5·9	22·19	57·8
	20	25·03	46·9	58·52	7·8	22·56	59·8
	30	25·20	48·9	58·79	9·8	22·91	62·2
June	9	25·33	50·9	59·04	11·9	23·23	64·9
	19	25·42	52·9	59·26	14·0	23·52	67·9
	29	25·48	54·9	59·44	16·2	23·77	71·2
July	9	25·50	56·7	59·59	18·3	23·96	74·6
	19	25·47	58·3	59·69	20·2	24·10	78·0
	29	25·41	59·8	59·75	22·0	24·18	81·4
Aug.	8	25·32	61·1	59·76	23·6	24·20	84·7
	18	25·19	62·1	59·74	25·1	24·18	87·8
	28	25·04	62·8	59·67	26·3	24·10	90·7
Sept.	7	24·87	63·3	59·56	27·3	23·96	93·3
	17	24·69	63·5	59·43	28·0	23·79	95·5
	27	24·51	63·4	59·28	28·5	23·58	97·4
Oct.	7	24·33	63·1	59·11	28·7	23·34	98·8
	17	24·17	62·5	58·94	28·7	23·08	99·8
	27	24·04	61·5	58·77	28·4	22·82	100·2
Nov.	6	23·94	60·3	58·62	27·9	22·56	100·2
	16	23·89	58·8	58·49	27·2	22·31	99·7
	26	23·88	57·1	58·39	26·2	22·09	98·7
Dec.	6	23·92	55·2	58·32	25·0	21·89	97·2
	16	24·01	52·9	58·29	23·7	21·73	95·2
	26	24·15	50·7	58·30	22·3	21·61	92·9
	36	24·32	48·6	58·35	20·7	21·54	90·3

USED IN DETERMINING THE LATITUDE BY OBSERVATIONS OF THE POLE STAR OUT OF THE MERIDIAN.

TABLE I.

Containing the *First* Correction.

Argument:—Sidereal Time of Observation.

Sidereal Time.	Correction.	Sidereal Time.	Sidereal Time.	Correction.	Sidereal Time.
h m	° ′ ″	h m	h m	° ′ ″	h m
0 0	− 1 15 45 +	12 0	6 0	− 0 25 43 +	18 0
10	1 16 48	10	10	0 22 23	10
20	1 17 42	20	20	0 19 1	20
30	1 18 28	30	30	0 15 36	30
40	1 19 4	40	40	0 12 10	40
50	1 19 31	50	50	0 8 43	50
1 0	1 19 50	13 0	7 0	0 5 14	19 0
10	1 19 59	10	10	− 0 1 45 +	10
20	1 19 59	20	20	+ 0 1 45 −	20
30	1 19 50	30	30	0 5 14	30
40	1 19 31	40	40	0 8 43	40
50	1 19 4	50	50	0 12 10	50
2 0	1 18 28	14 0	8 0	0 15 36	20 0
10	1 17 42	10	10	0 19 1	10
20	1 16 48	20	20	0 22 23	20
30	1 15 45	30	30	0 25 43	30
40	1 14 34	40	40	0 29 0	40
50	1 13 14	50	50	0 32 13	50
3 0	1 11 45	15 0	9 0	0 35 23	21 0
10	1 10 8	10	10	0 38 29	10
20	1 8 24	20	20	0 41 30	20
30	1 6 31	30	30	0 44 27	30
40	1 4 31	40	40	0 47 18	40
50	1 2 23	50	50	0 50 4	50
4 0	1 0 9	16 0	10 0	0 52 45	22 0
10	0 57 47	10	10	0 55 19	10
20	0 55 19	20	20	0 57 47	20
30	0 52 45	30	30	1 0 9	30
40	0 50 4	40	40	1 2 23	40
50	0 47 18	50	60	1 4 31	50
5 0	0 44 27	17 0	11 0	1 6 31	23 0
10	0 41 30	10	10	1 8 24	10
20	0 38 29	20	20	1 10 8	20
30	0 35 23	30	30	1 11 45	30
40	0 32 13	40	40	1 13 14	40
50	0 29 0	50	50	1 14 34	50
6 0	− 0 25 43 +	18 0	12 0	+ 1 15 45 −	24 0

TABLE II.

Containing the *Second* Correction (*always to be added.*)

Arguments:—Sidereal Time and Altitude.

Sidereal Time.	Altitude. 0°	5°	10°	15°	20°	25°	30°	35°	Sidereal Time.
h m	′ ″	″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	h m
0 0	0 0	0 1	0 1	0 2	0 2	0 3	0 3	0 4	12 0
30	0 0	0 0	0 0	0 1	0 1	0 1	0 1	0 1	30
1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	13 0
30	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	30
2 0	0 0	0 0	0 0	0 1	0 1	0 1	0 1	0 1	14 0
30	0 0	0 1	0 1	0 2	0 2	0 3	0 3	0 4	30
3 0	0 0	0 1	0 2	0 3	0 4	0 5	0 6	0 8	15 0
30	0 0	0 2	0 3	0 5	0 6	0 8	0 10	0 12	30
4 0	0 0	0 2	0 4	0 7	0 9	0 11	0 14	0 17	16 0
30	0 0	0 3	0 6	0 8	0 11	0 15	0 18	0 22	30
5 0	0 0	0 3	0 7	0 10	0 14	0 18	0 22	0 27	17 0
30	0 0	0 4	0 8	0 12	0 16	0 21	0 26	0 31	30
6 0	0 0	0 4	0 9	0 13	0 18	0 23	0 29	0 35	18 0
30	0 0	0 5	0 9	0 14	0 20	0 25	0 31	0 38	30
7 0	0 0	0 5	0 10	0 15	0 20	0 26	0 32	0 39	19 0
30	0 0	0 5	0 10	0 15	0 20	0 26	0 32	0 39	30
8 0	0 0	0 5	0 9	0 14	0 20	0 25	0 31	0 38	20 0
30	0 0	0 4	0 9	0 13	0 18	0 23	0 29	0 35	30
9 0	0 0	0 4	0 8	0 12	0 16	0 21	0 26	0 31	21 0
30	0 0	0 3	0 7	0 10	0 14	0 18	0 22	0 27	30
10 0	0 0	0 3	0 6	0 8	0 11	0 15	0 18	0 22	22 0
30	0 0	0 2	0 4	0 7	0 9	0 11	0 14	0 17	30
11 0	0 0	0 2	0 3	0 5	0 6	0 8	0 10	0 12	23 0
30	0 0	0 1	0 2	0 3	0 4	0 5	0 6	0 8	30
12 0	0 0	0 1	0 1	0 2	0 2	0 3	0 3	0 4	24 0

TABLE III. (*for* 1880.)

Containing the *Third* Correction (*always to be added.*)

Arguments:—Sidereal Time and Date.

Sidereal Time.	Jan. 1.	Feb. 1.	March 1.	April 1.	May 1.	June 1.	July 1.
h	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″
0	1 34	1 31	1 24	1 14	1 6	1 2	1 4
2	1 36	1 38	1 34	1 26	1 17	1 9	1 6
4	1 28	1 35	1 36	1 31	1 23	1 13	1 6
6	1 13	1 22	1 28	1 28	1 23	1 14	1 4
8	0 54	1 4	1 12	1 17	1 17	1 11	1 2
10	0 37	0 46	0 53	1 2	1 6	1 5	0 59
12	0 26	0 29	0 37	0 46	0 54	0 58	0 56
14	0 24	0 22	0 26	0 34	0 43	0 51	0 54
16	0 32	0 25	0 24	0 29	0 37	0 47	0 54
18	0 47	0 38	0 32	0 32	0 37	0 46	0 56
20	1 6	0 56	0 48	0 43	0 43	0 49	0 58
22	1 23	1 14	1 7	0 58	0 54	0 55	1 1
24	1 34	1 31	1 24	1 14	1 6	1 2	1 4

TABLE II.
Containing the *Second* Correction (*always to be added.*)
Arguments:—Sidereal Time and Altitude.

Sidereal Time.	Altitude. 35°	40°	45°	50°	55°	60°	65°	70°	Sidereal Time.
h m	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	h m
0 0	0 4	0 5	0 6	0 7	0 8	0 10	0 12	0 16	12 0
30	0 1	0 2	0 2	0 3	0 3	0 4	0 5	0 6	30
1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 1	0 1	13 0
30	0 0	0 0	0 0	0 0	0 0	0 0	0 1	0 1	30
2 0	0 1	0 2	0 2	0 3	0 3	0 4	0 5	0 6	14 0
30	0 4	0 5	0 6	0 7	0 8	0 10	0 12	0 16	30
3 0	0 8	0 9	0 11	0 13	0 16	0 19	0 23	0 30	15 0
30	0 12	0 14	0 17	0 21	0 25	0 30	0 37	0 47	30
4 0	0 17	0 20	0 24	0 29	0 35	0 42	0 52	1 7	16 0
30	0 22	0 26	0 32	0 38	0 45	0 55	1 8	1 27	30
5 0	0 27	0 32	0 39	0 46	0 55	1 7	1 23	1 46	17 0
30	0 31	0 38	0 45	0 54	1 4	1 18	1 36	2 3	30
6 0	0 35	0 42	0 50	1 0	1 12	1 27	1 47	2 18	18 0
30	0 38	0 45	0 54	1 4	1 17	1 33	1 55	2 28	30
7 0	0 39	0 47	0 56	1 6	1 19	1 36	1 59	2 33	19 0
30	0 39	0 47	0 56	1 6	1 19	1 36	1 59	2 33	30
8 0	0 38	0 45	0 54	1 4	1 17	1 33	1 55	2 28	20 0
30	0 35	0 42	0 50	1 0	1 12	1 27	1 47	2 18	30
9 0	0 31	0 38	0 45	0 54	1 4	1 18	1 36	2 3	21 0
30	0 27	0 32	0 39	0 46	0 55	1 7	1 23	1 46	30
10 0	0 22	0 27	0 32	0 38	0 45	0 55	1 8	1 27	22 0
30	0 17	0 20	0 24	0 29	0 35	0 42	0 52	1 7	30
11 0	0 12	0 14	0 17	0 21	0 25	0 30	0 37	0 47	23 0
30	0 8	0 9	0 11	0 13	0 16	0 19	0 23	0 30	30
12 0	0 4	0 5	0 6	0 7	0 8	0 10	0 12	0 16	24 0

TABLE III. (*for* 1880.)
Containing the *Third* Correction (*always to be added.*)
Arguments:—Sidereal Time and Date.

Sidereal Time.	July 1.	Aug. 1.	Sept. 1.	Oct. 1.	Nov. 1.	Dec. 1.	Dec. 31.
h	′ ″	′ ″	′ ″	′ ″	′ ″	″	′ ″
0	1 4	1 11	1 21	1 32	1 44	1 52	1 55
2	1 6	1 7	1 13	1 23	1 34	1 44	1 52
4	1 6	1 1	1 2	1 7	1 15	1 25	1 35
6	1 4	0 55	0 50	0 49	0 52	1 0	1 9
8	1 2	0 51	0 41	0 34	0 32	0 34	0 40
10	0 59	0 48	0 37	0 26	0 18	0 15	0 17
12	0 56	0 49	0 39	0 28	0 16	0 8	0 5
14	0 54	0 53	0 47	0 37	0 26	0 16	0 8
16	0 54	0 59	0 58	0 53	0 45	0 35	0 25
18	0 56	1 5	1 10	1 11	1 8	1 1	0 51
20	0 58	1 9	1 19	1 26	1 28	1 26	1 20
22	1 1	1 12	1 23	1 34	1 42	1 45	1 43
24	1 4	1 11	1 21	1 32	1 44	1 52	1 55

II.

MARCH, 1881.

AT MEAN NOON.							
Day of the Week.	Day of the Month.	THE SUN'S Apparent Declination.	THE SUN'S Var. in 1 hour.	Equation of Time, *to be subtracted from Mean Time.*	Var. in 1 hour.	Sidereal Time.
		° ′ ″	″	m s	s	h m s
Sun.	27	N. 2 45 59·5	58·65	5 21·64	0·765	0 20 13·02
Mon.	28	3 9 25·6	58·50	5 3·29	0·764	0 24 9·57
Tues.	29	3 32 48·1	58·34	4 44·98	0·761	0 28 6·13

AUGUST, 1881.

Mon.	1	N. 17 56 8·1	38·05	6 4·48	0·154	8 40 55·62
Tues.	2	17 40 46·0	38·78	6 0·47	0·180	8 44 52·18
Wed.	3	17 25 6·8	39·49	5 55·84	0·206	8 48 48·74
Thur.	4	17 9 10·7	40·18	5 50·59	0·231	8 52 45·29

OCTOBER, 1881.

AT MEAN NOON.						
Day of the Week.	Day of the Month.	THE SUN'S Apparent Declination.	THE SUN'S Var. in 1 Hour.	Equation of Time, *to be added to Mean Time.*	Var. in 1 Hour.	Sidereal Time.
		° ′ ″	″	m s	s	h m s
Sun.	23	S. 11 33 44·2	52·50	+15 37·21	0·324	14 8 9·55
Mon.	24	11 54 39·0	52·06	15 44·61	0·294	14 12 6·11
Tues.	25	12 15 22·8	51·59	15 51·31	0·264	14 16 2·66

NOVEMBER, 1881.

Thur.	17	S. 19 6 19·6	36·30	14 48·87	0·516	15 46 43·43
Frid.	18	19 20 40·2	35·44	14 36·06	0·551	15 50 39·98
Sat.	19	19 34 39·9	34·56	14 22·40	0·586	15 54 36·54

APPARENT PLACES OF STARS, 1881. 345

AT UPPER TRANSIT AT GREENWICH.

Month and Day.		α Ursæ Majoris. R.A.	α Ursæ Majoris. Dec. N.	α Crucis (Mean.) R.A.	α Crucis (Mean.) Dec. S.	α Virginis. (Spica) R.A.	α Virginis. (Spica) Dec. S.
		h m 10 56	° ′ 62 22	h m 12 20	° ′ 62 26	h m 13 18	° ′ 10 32
		s	″	s	″	s	″
Jan.	1	25·02	70·3	1·25	12·2	56·36	27·5
	11	25·55	70·7	1·83	14·2	56·69	29·5
	21	26·02	71·6	2·37	16·7	57·02	31·5
	31	26·42	73·0	2·86	19·5	57·33	33·4
Feb.	10	26·74	74·9	3·29	22·7	57·62	35·2
	20	26·96	77·1	3·64	26·0	57·87	36·9
Mar.	2	27·09	79·6	3·92	29·5	58·09	38·3
	12	27·12	82·2	4·13	33·0	58·27	39·5
	22	27·06	84·8	4·26	36·5	58·42	40·5
Apr.	1	26·92	87·4	4·32	39·9	58·53	41·3
	11	26·70	89·8	4·32	43·1	58·61	41·8
	21	26·43	91·8	4·26	46·1	58·66	42·1
May	1	26·12	93·6	4·13	48·8	58·68	42·3
	11	25·78	94·9	3·95	51·1	58·68	42·3
	21	25·43	95·8	3·74	53·1	58·66	42·1
	31	25·07	96·2	3·48	54·6	58·61	41·9
June	10	24·73	96·1	3·19	55·6	58·55	41·5
	20	24·40	95·5	2·88	56·2	58·47	41·1
	30	24·11	94·5	2·55	56·3	58·38	40·5
July	10	23·85	93·0	2·22	55·9	58·27	39·9
	20	23·63	91·1	1·89	55·0	58·16	39·3
	30	23·46	88·9	1·58	53·6	58·04	38·6
Aug.	9	23·35	86·3	1·30	51·9	57·93	37·9
	19	23·29	83·5	1·06	49·8	57·82	37·2
	29	23·30	80·5	0·87	47·4	57·72	36·6
Sept.	8	23·37	77·0	0·74	44·8	57·64	36·1
	18	23·51	73·6	0·69	42·0	57·59	35·7
	28	23·71	70·3	0·72	39·1	57·57	35·4
Oct.	8	23·99	67·0	0·85	36·5	57·59	35·3
	18	24·33	63·8	1·07	34·1	57·66	35·5
	28	24·73	60·8	1·38	32·1	57·77	35·9
Nov.	7	25·20	58·0	1·77	30·4	57·93	36·6
	17	25·72	55·6	2·24	29·3	58·13	37·6
	27	26·27	53·6	2·77	28·7	58·38	38·9
Dec.	7	26·85	52·0	3·34	28·7	58·66	40·4
	17	27·44	51·0	3·93	29·4	58·97	42·1
	27	28·02	50·5	4·53	30·6	59·30	43·9
	37	28·57	50·6	5·12	32·3	59·63	45·9

MARS, 1881. MEAN TIME.	Apparent Declination. Noon.
July 3	13 4 3·4
4	N. 13 18 2·7

II. FEBRUARY, 1882.

AT MEAN NOON.						
Day of the Week.	Day of the Month.	THE SUN'S Apparent Declination.	THE SUN'S Var. in 1 hour.	Equation of Time, *to be subtracted from Mean Time.*	Var. in 1 hour.	Sidereal Time.
		° ′ ″	″	m s	s	h m s
Sun.	26	8 38 20·1	56·14	13 4·60	0·433	22 24 55·61
Mon.	27	8 15 49·0	56·44	12 53·92	0·456	22 28 52·16
Tues.	28	7 53 10·8	56·73	12 42·69	0·479	22 32 48·71

APPARENT PLACES OF STARS, 1882. 333

AT UPPER TRANSIT OF GREENWICH.			
Month and Day		α Canis Minoris. (*Procyon*) R.A.	α Canis Minoris. (*Procyon*) Dec. N.
		h m	° ′
		7 33	5 31
		s	″
Jan.	1	9·89	24·7
	11	10·01	23·4
	21	10·09	22·2
	31	10·12	21·2
Feb.	10	10·10	20·4
	20	10·03	19·8
Mar.	2	9·92	19·3
	12	9·78	19·1

SATURN, 1882. 259

MEAN TIME.			
Month and Day.		*Apparent* Right Ascension. *Noon.*	*Apparent* Declination. *Noon.*
		h m s	° ′ ″
Feb.	26	2 24 45·00	12 1 16·2
	27	2 25 4·46	12 3 7·8
	28	2 25 24·22	N. 12 5 0·6

For converting INTERVALS of MEAN SOLAR Time into Equivalent INTERVALS of SIDEREAL Time.

HOURS.				MINUTES.						SECONDS.			
Hours of Mean Time.	Equivalents in Sidereal Time.			Minutes of Mean Time.	Equivalents in Sidereal Time.		Minutes of Mean Time.	Equivalents in Sidereal Time.		Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.
	h	m	s		m	s		m	s		s		s
1	1	0	9·8565	1	1	0·1643	31	31	5·0925	1	1·0027	31	31·0849
2	2	0	19·7130	2	2	0·3286	32	32	5·2568	2	2·0055	32	32·0176
3	3	0	29·5694	3	3	0·4928	33	33	5·4211	3	3·0082	33	33·0904
4	4	0	39·4259	4	4	0·6571	34	34	5·5853	4	4·0110	34	34·0931
5	5	0	49·2824	5	5	0·8214	35	35	5·7496	5	5·0137	35	35·0958
6	6	0	59·1388	6	6	0·9857	36	36	5·9139	6	6·0164	36	36·0986
7	7	1	8·9953	7	7	1·1499	37	37	6·0782	7	7·0192	37	37·1013
8	8	1	18·8518	8	8	1·3142	38	38	6·2424	8	8·0219	38	38·1040
9	9	1	28·7083	9	9	1·4785	39	39	6·4067	9	9·0246	39	39·1068
10	10	1	38·5647	10	10	1·6428	40	40	6·5710	10	10·0274	40	40·1095
11	11	1	48·4212	11	11	1·8070	41	41	6·7353	11	11·0301	41	41·1123
12	12	1	58·2777	12	12	1·9713	42	42	6·8995	12	12·0329	42	42·1150
13	13	2	8·1342	13	13	2·1356	43	43	7·0638	13	13·0356	43	43·1177
14	14	2	17·9906	14	14	2·2998	44	44	7·2281	14	14·0383	44	44.1205
15	15	2	27·8471	15	15	2·4641	45	45	7·3924	15	15·0411	45	45·1232
16	16	2	37·7036	16	16	2·6284	46	46	7·5566	16	16·0438	46	46·1259
17	17	2	47·5600	17	17	2·7927	47	47	7·7209	17	17·0465	47	47·1287
18	18	2	57·4165	18	18	2·9569	48	48	7·8852	18	18·0493	48	48·1314
19	19	3	7·2730	19	19	3·1212	49	49	8·0495	19	19·0520	49	49·1342
20	20	3	17·1259	20	20	3·2855	50	50	8·2137	20	20·0548	50	50·1369
21	21	3	26·9859	21	21	3·4498	51	51	8·3780	21	21·0575	51	51·1396
22	22	3	36·8424	22	22	3·6140	52	52	8·5423	22	22·0602	52	52·1424
23	23	3	46·6989	23	23	3·7783	53	53	8·7066	23	23·0630	53	53·1451
24	24	3	56·5554	24	24	3·9426	54	54	8·8708	24	24·0657	54	54·1479
				25	25	4·1069	55	55	9·0351	25	25·0685	55	55·1506
				26	26	4·2711	56	56	9·1994	26	26·0712	56	56·1533
				27	27	4·4354	57	57	9·3637	27	27·0739	57	57·1561
				28	28	4·5997	58	58	9·5279	28	28·0767	58	58·1588
				29	29	4·7640	59	59	9·6922	29	29·0794	59	59·1615
				30	30	4·9282	60	60	9·8565	30	30·0821	60	60·1643

SAFE NAVIGABLE TRANSATLANTIC DISTANCES IN CLEAR WEATHER.

(NAUTICAL MILES)

CALCULATED BY CAPTAIN LECKY, R.N.R.,

Marine Superintendent, Great Western Railway.

PORTS.	QUEENSTOWN (Roches Point).	MILFORD (Newton Noyes Pier).	NEW MILFORD (Pontoons).	FISHGUARD (Breakwater).	FALMOUTH (St. Anthony Point).	HOLYHEAD (Breakwater) *Via* Fastnet.	PLYMOUTH (Breakwater).	BRISTOL (Avonmouth Docks).	LIVERPOOL (Rock Light) *Via* Innistrahull.	LIVERPOOL (Rock Light) *Via* Fastnet.	PORTLAND (Breakwater).	SOUTHAMPTON (Empress Dock).	LONDON (Tilbury Docks).	LONDON (Royal Albert Docks).
PASPEBIAC (in Chaleur Bay) *Via* Straits of Belle Isle.	2187	2303	2306	2307	2341	2356	2373	2391	2344	2420	2444	2492	2659	2672
HALIFAX (Deep-water Terminus, Intercolonial Railway).	2231	2346	2349	2351	2374	2400	2405	2434	2437	2464	2476	2524	2691	2704
PASPEBIAC (in Chaleur Bay) *Via* Cape Race.	2281	2397	2400	2401	2424	2450	2456	2485	2488	2514	2527	2575	2742	2755
QUEBEC (Allan Line Wh.) South of Anticosti, *Via* Straits of Belle Isle.	2473	2588	2591	2593	2627	2642	2659	2677	2630	2706	2730	2778	2945	2958
BOSTON (Docks).	2584	2700	2703	2704	2727	2753	2759	2788	2791	2817	2830	2878	3045	3058
QUEBEC (Allan Line Wh.) South of Anticosti, *Via* Cape Race.	2595	2710	2713	2715	2738	2764	2770	2798	2801	2828	2841	2889	3056	3069
FORT POND (near Montauk Point).	2682	2797	2800	2802	2825	2851	2857	2885	2888	2915	2928	2976	3143	3156
NEW YORK (Jersey City Ferry).	2782	2897	2900	2902	2925	2951	2957	2985	2988	3015	3028	3076	3243	3256
PHILADELPHIA (American Line Dock).	2932	3047	3050	3052	3076	3101	3108	3135	3138	3165	3179	3227	3393	3406

" Lane routes," and ice at certain seasons are not taken into account.

SOME CROSS-CHANNEL DISTANCES.

ENGLAND TO IRELAND.

	Nautical Miles.
Bristol to Rosslare	161·0
„ Cork	235·0
New Milford to Rosslare	65·0
„ Wexford	74·0
„ Waterford	98·0
„ Roche's Point	125·0
„ Queenstown	129·2
„ Fastnet Lighthouse	176·5
St Ann's Head to Hook Tower	70·7
Fishguard to Rosslare	54·0
„ Waterford (daylight)	90·7
„ „	92·0
„ Dublin	95·5
„ Fastnet Lighthouse	178·0
Holyhead to Kingstown	57·0
„ Dublin	60·0
Liverpool to Dublin	120·0
„ Drogheda	120·0
„ Dundalk	124·5
„ Newry	128·5
„ Belfast	135·0
„ Rosslare	154·5
Fleetwood to Belfast	118·0
Stranraer to Larne	34·0

ENGLAND TO THE CHANNEL ISLANDS.

New Milford to St. Heliers	266·0 approx.
Dartmouth to St. Peter Port (*via* Little Russel)	70·2
„ „ (*via* S. Coast of Guernsey)	74·7
Weymouth to St. Peter Port	71·3
„ St. Heliers (direct)	95·0
„ „ (*via* Guernsey)	98·0
Southampton to St. Peter Port	104·0
„ St. Heliers direct (*via* Race of Alderney)	122·5
„ „ (*via* Casquets & Guernsey)	130·7
Spithead, Horse sand fort (*via* Needles and Race of Alderney) to St. Heliers	125·0 approx.

BETWEEN THE CHANNEL ISLANDS.

	Nautical Miles.
St. Peter Port to St. Heliers	26·7
„ Sark *and back*	19·0
„ Alderney	23·0
„ round Guernsey *and back* ...	27·0
Sark to Alderney	21·5 approx.
St. Heliers to Sark	22·0
„ Alderney	43·0
„ round Jersey *and back*	37·0

CHANNEL ISLANDS TO FRANCE.

St. Peter Port to St. Malo direct (W. of Minquiers) ...	55·0
„ „ calling at St. Heliers	63·0
„ Granville direct (E. of Minquiers) ...	55·0
„ „ calling at St. Heliers	57·0
St. Heliers to St. Malo (E. of Minquiers) ...	37·0
„ „ (over the Minquiers) ...	34·0
„ Granville (direct)	30·0
„ Cherbourg	58·0 approx.
„ St. Brieuc	49·0
„ Morlaix	87·0

St. Heliers to St. Malo ...	37·0	The round trip ...	89·0
St. Malo to Granville ...	22·0		
Granville to St. Heliers ...	30·0		

Alderney to Cherbourg	22·5 approx.

ENGLAND TO FRANCE AND THE CONTINENT.

	Nautical Miles.
Weymouth to Cherbourg	68·0
„ St. Malo direct	124·0
„ St. Brieuc	128·0
„ Morlaix	137·0
„ Brest	207·0
Southampton to Havre	106·2
„ St. Malo	151·0
Newhaven to Dieppe	65·5
Folkestone to Boulogne	26·3
Dover to Calais	22·0
„ Ostend	62·3
Queenboro' to Flushing	114·0

England to France and the Continent *(continued).*

	Nautical Miles.
Harwich to Hook of Holland	109·7
„ Rotterdam	125·0
„ Antwerp	140·0
„ Hamburg	365·0

BETWEEN VARIOUS ENGLISH PORTS.

New Milford to the Lizard ...	134·7	
Lizard to Penlee Point	46·0	
Penlee Point to Mill Bay Dock...	3·7	
New Milford to Mill Bay Dock		184·4
New Milford to St. Ann's ...	10·0	
St. Ann's to Longships	101·0	
Longships to Lizard	23·5	
Lizard to Start Point	63·5	
Start Point to Portland Bill ...	49·5	
Portland Bill to Weymouth ...	7·0	
New Milford to Weymouth		254·0
New Milford to Tenby (Pier)		33·0
„ Fishguard		43·5
„ Llanelly (G. W. R. Dock) ...		50·0
„ Swansea Roads		58·0
„ Porthcawl		66·0
„ Cardiff (Bute Dock)		93·0
„ Avonmouth Dock		108·0
„ Bristol		113·5
Weymouth to Start Point ...	56·5	
Start Point to Mill Bay Dock ...	25·5	
Weymouth to Mill Bay Dock		82·0
Weymouth to Southampton, Empress Dock ...		55·0
Saltney to Dee Light-Vessel ...	23·0	
Dee Light-Vessel to Chester Bar Buoy	7·0	
Chester Bar Buoy to Holyhead...	46·0	
Saltney to Holyhead		76·0
Saltney to Hilbre Island... ...	23·0	
Hilbre Island to Rock Light ...	15·0	
Saltney to Liverpool		38·0
Penzance to St. Mary's (Scilly) by N. channel ...		35·7
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WRINKLES

IN

PRACTICAL NAVIGATION.

BY CAPTAIN S. T. S. LECKY.

Soon after publication this work was supplied to the vessels of the United States Navy, by order of the Bureau of Navigation, Washington, D.C.; and by Admiralty order it was subsequently supplied to vessels of the Royal Navy. It has been adopted by the Trinity House of London, and by many of the large ship-owning companies of England.

OPINIONS OF THE PRESS ON PREVIOUS EDITIONS.

"'Wrinkles,' what a misnomer! Why the book is far more calculated to remove them than to pucker the face of the reader. Here you have a real comfort to the seaman; many a knotty point of his profession put before him in a readable form, so that, so far from being worried, he is inclined, like Sam Weller over his love-letter, to wish 'there was more.' The author disclaims any literary merit in his book on the score of roughing it at sea since the age of thirteen; but he might have left this to the critic to find out, for assuredly few more useful, practical, and well-written additions to the sailor's library have appeared for many a long year than the 'Wrinkles' now before us. No officer in the Mercantile Marine, or rather no merchant ship, should sail without this volume on board. The amount of instruction to be derived from it would surprise, and pleasurably surprise, most seamen. We hope 'Wrinkles' will soon come into general demand, and indeed it should be made a text-book on board the *Conway* and *Worcester* without loss of time."—*Colburn's United Service Magazine.*

"One of the wisest of modern aphorisms is the dictum that 'Every man is a debtor to his profession;' and in the present volume Captain Lecky has paid what we hope is not his last instalment.

"We may say at once that this is an admirable book. . . . .

"The author, like a good workman, starts with a review of his tools (books and instruments), and pithily observes:—'There are so many works on navigation that any one so disposed might easily convert his cabin into a book closet, leaving no room to stow away himself and wardrobe.' He gives a list of 16 books, costing about £8. . . . .

"Chapter XV. is devoted to what the author calls 'Weatherology,' and we think it one of the best in the book. As might be expected, the author thinks that the best system of all is constant watchfulness.

". . . . . In taking leave of this valuable book, the reviewer has to say, in conclusion, that should it be his fate again to plough the waters for a livelihood, he shall certainly add to his library 'Captain Lecky's Wrinkles in Practical Navigation,' even at the risk of 'leaving no room to stow away himself and wardrobe.'"—*Mercantile Marine Service Association REPORTER.*

"Captain Lecky devotes his book to practical Navigation. He has dedicated his work to Sir Thomas Brassey, in memory of having had a place in the *Sunbeam* during a portion of her adventurous voyage. The author tells us that the book has been prepared for comparatively young members of the profession, and that 'one of the leading objects has been to elucidate in plain English some of those important elementary principles which the *savants* have enveloped in such a haze of mystery as to render pursuit hopeless to any but a skilled mathematician.' That Captain Lecky has performed this task carefully and effectually will be admitted by all who are competent to consult and to give an opinion on his pages. In the appendix will be found some pretty formulæ for correcting the rate of a marine chronometer, with examples to be worked out; also a table of corrections due to changes of temperature; some information respecting what is known as the 'heeling error' in the compasses of iron ships, and other

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OPINIONS OF THE PRESS—*Continued.*

'mportant matters. Captain Lecky's work does not aim at novel theories or recondite disquisitions on questions of navigation; but it is a practical and useful production, and as such will, we have no doubt, be appreciated by those for whom it is intended."—*Shipping and Mercantile Gazette.*

"A pleasant feature in the work is that, written in homely language, thoroughly familiar to the nautical ear, it is never too learned. None of the 'Wrinkles' are surrounded by that husk of mathematical mystery with which some of our modern *savants* love to shroud the information they are seeming to give, and puzzle rather than instruct their readers. . . . .

"The entire work is so well worthy of attention that it seems unfair to especialise any particular chapter. We should advise sailors to thoroughly study the whole book, from the Preface to Appendix D."—*British Merchant Service Journal.*

"The author of this work states in his preface that 'the particular aim of the treatise is to furnish seamen with thoroughly *practical* hints, such as are not found in the ordinary works on Navigation,' and he has stuck to his text. The work abounds in excellent and sound advice on every subject and science with which a navigator should be acquainted; and in discussing instruments, books, and methods, though there are no novelties, there is much practical information that will be serviceable alike to old and young."—*Nautical Magazine.*

"The great charm of the work is that the author does not ascend to what some term the scientific; he is never too learned, but has well carried out the task he sets himself in the preface.

"In a pleasant, attractive, and sailor-like style he deals with what Captain Bedford, in the 'Sailor's Pocket Book,' so well terms 'the important simplicities' of navigation. The mariner's compass, the sextant, chronometer, chart, dividers, parallel rulers, log and lead, station pointer, barometer and thermometer, are each in turn treated upon, and valuable 'wrinkles' with regard to their manipulation and individual peculiarities are given to the public.

"These 'wrinkles' are the result of the observations of a sailor who has not only gone to sea with his eyes open, but who also has had the industry to read and weigh the opinions of others.

"The student of 'Wrinkles' will not only derive advantage from the experience of its observant author, but he will also find himself introduced to the best men and works connected with the instruments and subjects treated upon. Numerous examples and illustrations illuminate the ordinary letterpress."—*United Service Gazette.*

"Nautical works are almost as 'plentiful as blackberries,' and it is rather difficult for an author in these days to bring anything before the public in the nautical way which has not already appeared in print. Captain Lecky has, however, proved that there is no rule without an exception, for his 'Wrinkles' in Practical Navigation is quite an exception to the general run of instructive books on navigation, for he takes the sailor from the 'cradle to the grave,' and tells him what to do when he first leaves the former until he finishes his education. The information conveyed in 'Wrinkles' is told in a thoroughly readable way, and put in a form at once concise and intelligible; and however full the seaman's library may be, we are sure that he cannot do better than find space on his book-shelf for 'Wrinkles in Practical Navigation.'"—*Hunt's Yachting Magazine.*

"Captain Lecky's 'Wrinkles' may be accepted with confidence; the vast amount of matter which the work contains is astonishing, but, after a careful perusal, competent readers will, we think, admit that not a single page has been penned in vain.

"The most ancient of mariners can, we believe, obtain from Captain Lecky's work a large supply of useful 'Wrinkles.'"—*Army and Navy Gazette.*

"A valuable addition to the science of practical navigation is the work under the above title by Captain Lecky of the American Steamship Line. Captain Lecky's announced purpose in the preparation of this volume 'is to furnish seamen with thoroughly *practical* hints, such as are not found in the ordinary works on navigation,' and he has accomplished this in a large degree, not the least valuable feature of his production being in numerous illustrations and diagrams, which ought to make their subjects clear to the dullest mind. The appearance of such a work on navigation should be warmly welcomed by seamen, whose arduous vocation generally prevents them from giving much thought or time to investigations other than those which lie near the surface of things.

"But the general public, as well as navigators, have much to learn from Captain Lecky's '*Wrinkles.*' The author conclusively demolishes the theory that in approaching icebergs thermometric tests of the water can be confidently relied on to reveal through darkness or fog the proximity of these floating dangers. He also throws out some valuable hints on fog navigation, and forcibly overthrows the plea for high speed in fogs, especially when near land, and trusting to that 'stupid old pilot—dead reckoning.' To the general reader his chapter on 'Weatherology' will present peculiar attractions. Captain Lecky has evidently been a keen weather observer at sea, and has informed himself of most that has been advanced by modern meteorologists on the 'law of storms.' It is to be regretted, however, both for science and seamanship, that he seems to underrate the benefits the navigator has derived, or is likely to

OPINIONS OF THE PRESS—*Continued.*

derive, from concerted meteorological observations on the ocean. 'If,' he says, 'concerted action avails so little, what chance has an isolated individual, such as the commander of a ship, who has nothing to guide him but his own local observations, of satisfying himself as to the weather he may expect for even a single coming day?' Captain Lecky overlooks the fact that, as yet no 'concerted action' for investigation of ocean meteorology at all commensurate with the magnitude of the marine storm-field has ever been taken; and, unhappily, while giving his nautical brethren minute instructions as to almost everything that concerns them to know or to do, he omits to spur them up to the work of co-operating in the great modern international scheme of marine weather-research, designed to supply the very lack he seemingly deplores. If Captain Lecky and half the commanders of the merchant marine, who will read his book with eager interest, would enter heartily on this observational work, and contribute their simultaneous ocean weather reports to the signal service, the results deduced from such co-operation might hasten that better day he hopes for, in which the seaman will not have to depend solely upon his own individual weather experience, but will go on his ocean course having his way, so to speak, 'blazed' through the winds and latitudes and longitudes, and will be in possession of knowledge by which he can, in a large degree, forecast to-morrow's 'probabilities.'"—*Public Ledger and Daily Transcript, Philadelphia.*

"A practical and direct help to merchant captains will be found in a work lately published by Messrs. George Philip & Son, of Fleet Street, London. The author, Captain S. T. S. Lecky, R.N.R., is well known in the mercantile marine as a careful, clever, and scientific navigator, and he has brought a large amount of his knowledge and practical ability to bear upon the present publication. The aim of the author has evidently been to convey, in simple language, thoroughly practical hints, and he has condensed, in a clear, succinct style, the teachings of standard works and the results of his own experience into a handy and clever work. The author states in his preface that 'The volume contains but little that is claimed as strictly original; it is based upon life-long observation, matter gleaned from the works of men of repute, and information derived from intercourse with shipmasters and the cloth generally.'—Notwithstanding this modest preface, Captain Lecky has thrown out some valuable hints, and has given his information in a very sensible form. This is particularly applicable to his selection of books necessary for reference and guidance, and his list of indispensable nautical instruments of navigation. The Chapter on the 'Mariner's Compass' contains a large amount of useful information, and will be read with interest by all practical navigators. His remarks on the marine chronometer, the sextant, and the artificial and sea-horizons, form the subjects of three very able chapters, and will well repay careful perusal. This applies also to his observations on the use of instruments, their adjustment, and comparative value, and, although there is little that is novel, his 'wrinkles' are given in a sailor-like and concise form. The astronomical portion of the volume is all good and practical, and such as all who have charge of life and property at sea should have a knowledge of. Especially clear and concise are his remarks on 'Latitude by meridian altitude,' and his 'Longitude by chronometer,' while those chapters devoted to the subjects of 'shaping a course,' and 'The danger angle and correct determination of distance from land,' will commend themselves to all practical and enquiring minds.

"The author has collected some useful notes on tides, currents, waves and breakers, which should be of much service to those interested in such physical phenomena.

"The book is well printed, and contains 70 or 80 illustrations, including some carefully executed physical maps."—*The Englishman, Calcutta.*

"This work is certainly the very best of its class ever emanating from a practical seaman, and to us it was a real source of pleasure to read it through, as we did from prefix to appendix. Captain Lecky has written in a charming, off-hand style, and from the start captures his reader and leads him on in deep interest through the thirty-three chapters of his work. He makes the study of navigation a real pleasure, and as attractive as a romance, yet full, practical, and correct. We claim to know something of 'navigation wrinkles,' but Captain Lecky has quickly and tersely taught us how little we really did know. He is not only a keen observer, but has cleverly adapted the good opinions of others, and blended them so adroitly with those of his own, which are ripened with experience, that the work stands without a peer in the literature of things pertaining to the science of navigation. There is no work that we know of that we can so urgently recommend to the practical navigator as this one. It is a library in itself. It is the work of a true sailor, and one whom we must esteem very highly for his superior talents and attainments. No work of its class ever received higher commendation from the British press than 'Wrinkles' has, and deservedly so. It is a work that can be understood by the professional mariner of any grade, and being devoid of the 'wholly too learned,' is suited to all degrees of progress in the study of navigation; and even the oldest master mariner can learn from its pages very much that is valuable, while to the 'youngster' it is invaluable. We hope our shipmasters will secure a copy of this work, and we feel assured that they will thank us for pointing out its existence and merits. Captain Lecky is now in command of one of the American Line steamers, and hence he is well posted in the Atlantic trade, and was in Sir Thomas Brassey's famous yacht *Sunbeam*, in her cruise around the world. We congratulate the captain upon the results of his labours, and he certainly deserves the thanks of his brethren everywhere."—*The Nautical Gazette* (New York).

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