CHAPTER VIII.

LONGITUDE BY CHRONOMETER.

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.

First meridian —the Royal Observatory at Greenwich.

With us this starting point is the meridian of the transit instrument at the Royal Observatory of Greenwich; and it is probable that, by international consent, this will in future be considered the *First Meridian* for the entire globe, and foreign charts graduated accordingly.

Longitude—how defined and measured

The *longitude* of a place, therefore, by our reckoning, may be defined as *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 Markham in the recent Arctic Expedition under Captain Sir George Nares—a degree of longitude is only 7 miles; and at the North Pole itself, in latitude 90°, longitude has no existence whatever, and the sun always bears true south during the six months of the year that it 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 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 question 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. These last, however, are rapidly dying out, and are mostly looked upon now as "fancy navigation." Excellent chronometers can be purchased brand new for £25 to £30; when second-hand, and equally good, for much less; in fact, they are becoming a drug in the market. The better class of vessels seldom carry fewer than three.

Money value of chronometers.

Till Harrison's invention of the first useful artificial marine chronometer was given to the world in 1765, through the well-judged beneficence of the British Government, the only chronometer generally available for finding longitude at sea was that great natural chronometer presented by the moon in her orbital motion round the earth.

Imagine a line joining the centres of inertia of the earth and moon to be, as it were, the hand of a great clock, revolving round the common centre of inertia of the two bodies, and shewing time on the background of stars for a dial.

"Lunar Theory."

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 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.

It is done, of course, 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 miles, by the method of lunars, in tropical seas, or within 10 miles 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. **Amount of dependence.**

To be able, therefore, to place any reliance on Lunars, requires a really first-class observer, and constant practice, and even then the results are at best but approximate, "inasmuch as the errors of observation are multiplied in their effects on the resulting longitude by a factor whose mean value is about 30; consequently an error of only 10″ in a Lunar Distance (and we presume that under the most favourable circumstances we have no right to expect less—and in most cases it would probably be very much more) becomes 300″ or 5′ in the resulting longitude deduced from it, and this, be it observed, is independent of an additional error of from 6′ to 8′ due to a small uncertainty still existing in the place of the moon as given in the Tables."* **Lunars almost obsolete.**

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."

Also in a footnote on page 333 of his 13th ed. we find the

* See Admiral Sir Chas. Shadwell "*On the Management of Chronometers.*"

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.

Lunar discrepancies.

Sir W. Thomson, 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."

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 "good old days" when ships were made snug for the night, and the East India "Tea-waggons" took a couple of years to make the round voyage.

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 others do so. Whether Lunars are worth cultivating or not may, in the minds of some people, still be open to question, but certain it is they have fallen into disuse, and, without in the least being endued with the mantle of prophecy, the writer ventures to say they will never be resurrectionised, for the best of all reasons—they are no longer required.

Nor is there the same necessity for them as of yore. Steam is superseding sail, and voyages generally are shorter than formerly. Now-a-days, also, as the longitude of most places on the globe has been correctly determined, there are infinitely greater opportunities for rating chronometers.

Thanks to the persevering research of Mr. Hartnup, the able astronomer at Bidston, who has 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. 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 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.

Differences of longitude, how determined *on shore*.

Instruments used.

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.

Actual mode of operation.

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.

Differences of longitude, how determined at sea. *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. (See Table II., page 291).

No direct ratio between errors of observation and errors in the result.

Proper time to take sights for longitude. *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.

Prime Vertical. 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.*

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 *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.

Latitude of but little importance when observation is made on the Prime Vertical.

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.

Good sights for longitude can *at times* be had within 10 or 20 minutes noon.

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.

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 IX. of Norie · 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. *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. *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 their 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.

It is *very* important that attention should be paid to this point in observing for time, as neglect of it may entail serious disaster.

Table shewing by inspection the Hour Angle and Alt. of a body when on the Prime Vertical. 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 *Norie's Navigation*, the table is numbered XLV.,* and in the one following will be found 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 IX.*, and all possibility of mistake thus avoided.

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 tables above specified: it is given on page xxxii. of Norie.

Another mode of ascertaining the time that a celestial object will bear east or west, is by reference to Burdwood's or Davis's

* Table XXIX. of Raper.

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 Norie, the limit for declination is 50°, and for latitude 70°.

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. This will be rendered clearer by supposing a case, and referring it to Burdwood or Davis.

Lat. and Declin. having *contrary* names—best time to observe.

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 7·36 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 just 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.

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 shews 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 the "Ex-meridian" might unavoidably be such, that without the *correct* time the result deduced might be considerably astray.

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 I., (pages 288, 289), inserted by the generous permission of its author,* gives the error of longitude due to an error of 1′ in the *Latitude*, for every second degree of bearing from 10° up to 90.° This is a most valuable table, shewing at a glance what to

* Mr. A. C. Johnson, R.N.

expect from an incorrect latitude. The writer, following up Mr. Johnson's idea, has had Table II., (pages 290, 291) computed for him by one of his officers, Mr. George C. Burton, which, in a similar manner to Table I., gives the approximate 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.*

Tables shewing errors in result due to errors of latitude and altitude.

To avoid confusing Table I. with Table II., the latter is printed in red ink.

Reference to the top right hand corner shews that in high latitudes, when the bearing is only 15° or 20° from the meridian, the error in the longitude may be very large—conceive, then, the difficulties of Polar navigation. Even in the very ordinary case given on page 231, where the morning sights were taken at 10·15 o'clock, 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 put the longitude out 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. To change the tabular values into seconds of time, multiply by 4.

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.

Folly of working to seconds of arc.

Nor is it necessary to take out the logarithms to more than five figures, any greater exactness being incompatible with the com-

* In this Edition, Table II. is quite accurate, having been kindly overhauled by Capt. S. P. H. Atkinson, who lent a hand with one or two other things which have also been improved upon.

TABLE I.

Showing the error in the Longitude produced by an error of 1′ in the Latitude.

Bearing.	LATITUDE. 0°	4°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°
10°	5′.67	5′.70	5′.73	5′.76	5′.79	5′.85	5′.91	5′.97	6′.03	6′.12	6′.21	6′.30	6′.42	6′.55	6′.69
12	4.71	4.72	4.75	4.78	4.81	4.85	4.89	4.95	5.01	5.08	5.16	5.28	5.34	5.43	5.55
14	4.01	4.02	4.04	4.06	4.09	4.12	4.16	4.20	4.26	4.32	4.38	4.46	4.54	4.63	4.73
16	3.49	3.50	3.52	3.54	3.56	3.59	3.62	3.66	3.70	3.76	3.82	3.88	3.94	4.02	4.11
18	3.08	3.09	3.11	3.13	3.15	3.18	3.20	3.24	3.28	3.32	3.37	3.43	3.49	3.55	3.63
20	2.75	2.76	2.78	2.79	2.81	2.83	2.86	2.89	2.92	2.96	3.01	3.06	3.12	3.17	3.24
22	2.47	2.47	2.48	2.50	2.52	2.54	2.57	2.60	2.63	2.66	2.70	2.75	2.80	2.86	2.92
24	2.25	2.26	2.27	2.28	2.30	2.32	2.34	2.37	2.39	2.43	2.46	2.50	2.55	2.59	2.65
26	2.05	2.05	2.07	2.08	2.10	2.11	2.13	2.15	2.18	2.21	2.24	2.28	2.32	2.37	2.42
28	1.88	1.88	1.90	1.91	1.92	1.94	1.96	1.98	2.00	2.03	2.06	2.09	2.13	2.17	2.22
30	1.73	1.73	1.75	1.76	1.77	1.78	1.80	1.82	1.84	1.87	1.89	1.92	1.96	2.00	2.04
32	1.60	1.60	1.62	1.63	1.64	1.65	1.66	1.68	1.70	1.73	1.75	1.78	1.81	1.85	1.89
34	1.48	1.48	1.49	1.50	1.51	1.53	1.54	1.56	1.57	1.60	1.62	1.65	1.68	1.71	1.75
36	1.38	1.38	1.39	1.40	1.41	1.42	1.44	1.45	1.47	1.49	1.51	1.53	1.55	1.59	1.62
38	1.28	1.28	1.28	1.29	1.30	1.31	1.32	1.34	1.35	1.37	1.39	1.41	1.44	1.48	1.51
40	1.19	1.19	1.20	1.21	1.22	1.23	1.24	1.25	1.27	1.28	1.30	1.32	1.35	1.38	1.41
42	1.11	1.11	1.12	1.13	1.14	1.14	1.15	1.17	1.18	1.20	1.22	1.24	1.26	1.28	1.31
44	1.04	1.04	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.12	1.13	1.15	1.17	1.20	1.22
46	0.97	0.97	0.98	0.98	0.99	1.00	1.01	1.02	1.03	1.04	1.06	1.07	1.09	1.11	1.14
48	0.90	0.90	0.91	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.99	1.00	1.02	1.04	1.06
50	0.84	0.84	0.85	0.85	0.86	0.87	0.87	0.88	0.89	0.91	0.92	0.93	0.95	0.97	0.99
52	0.78	0.78	0.79	0.79	0.80	0.80	0.81	0.82	0.83	0.84	0.85	0.87	0.88	0.90	0.92
54	0.73	0.73	0.73	0.74	0.74	0.75	0.75	0.76	0.77	0.78	0.79	0.81	0.82	0.84	0.86
56	0.67	0.67	0.68	0.68	0.69	0.69	0.70	0.71	0.71	0.72	0.73	0.75	0.77	0.78	0.79
58	0.63	0.63	0.63	0.63	0.64	0.64	0.65	0.66	0.66	0.67	0.68	0.69	0.71	0.72	0.74
60	0.58	0.58	0.59	0.59	0.59	0.60	0.60	0.61	0.62	0.62	0.63	0.65	0.66	0.67	0.68
62	0.53	0.53	0.54	0.54	0.54	0.55	0.55	0.56	0.56	0.57	0.58	0.59	0.60	0.61	0.63
64	0.49	0.49	0.50	0.50	0.50	0.51	0.51	0.52	0.52	0.53	0.54	0.55	0.56	0.56	0.57
66	0.45	0.45	0.45	0.45	0.46	0.46	0.46	0.47	0.47	0.48	0.49	0.50	0.50	0.51	0.52
68	0.40	0.40	0.40	0.41	0.41	0.41	0.42	0.42	0.43	0.43	0.44	0.45	0.45	0.47	0.47
70	0.36	0.36	0.36	0.37	0.37	0.37	0.37	0.38	0.38	0.39	0.39	0.40	0.41	0.42	0.43
72	0.33	0.33	0.33	0.33	0.34	0.34	0.34	0.34	0.35	0.35	0.36	0.36	0.37	0.37	0.38
74	0.29	0.29	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.31	0.32	0.32	0.33	0.33	0.34
76	0.25	0.25	0.25	0.25	0.25	0.26	0.27	0.27	0.27	0.27	0.27	0.28	0.28	0.29	0.29
78	0.21	0.21	0.21	0.21	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.25
80	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.20	0.20	0.20	0.21
82	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.17
84	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12
86	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08
88	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
89	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE I.

Showing the error in the Longitude produced by an error of* 1′ *in the Latitude.

Bearing.	LATITUDE.													
	34°	36°	38°	40°	42°	44°	46°	48°	50°	52°	54°	56°	58°	60°
10°	6·84	7·01	7·20	7·40	7·63	7·88	8·16	8·48	8·82	9·21	9·65	10·14	10·70	11·33
12	5·67	5·81	5·97	6·14	6·33	6·54	6·77	7·03	7·32	7·64	8·00	8·41	8·88	9·41
14	4·84	4·95	5·09	5·23	5·40	5·58	5·77	5·99	6·24	6·51	6·82	7·17	7·57	8·02
16	4·21	4·31	4·43	4·55	4·69	4·85	5·02	5·21	5·42	5·66	5·93	6·24	6·58	6·97
18	3·71	3·80	3·90	4·02	4·14	4·28	4·43	4·60	4·79	5·00	5·24	5·50	5·81	6·15
20	3·31	3·39	3·49	3·59	3·70	3·82	3·95	4·11	4·27	4·46	4·67	4·91	5·19	5·49
22	2·98	3·06	3·14	3·23	3·33	3·44	3·56	3·70	3·85	4·02	4·21	4·43	4·67	4·95
24	2·71	2·77	2·85	2·93	3·02	3·12	3·23	3·36	3·49	3·65	3·82	4·02	4·24	4·49
26	2·47	2·53	2·60	2·68	2·76	2·85	2·95	3·06	3·19	3·33	3·49	3·66	3·87	4·10
28	2·27	2·32	2·39	2·45	2·53	2·61	2·71	2·81	2·92	3·05	3·20	3·36	3·55	3·76
30	2·09	2·14	2·20	2·26	2·33	2·41	2·49	2·60	2·69	2·81	2·95	3·10	3·27	3·46
32	1·93	1·98	2·03	2·09	2·15	2·22	2·30	2·39	2·49	2·60	2·72	2·86	3·02	3·20
34	1·79	1·83	1·88	1·93	1·99	2·06	2·13	2·22	2·31	2·41	2·52	2·65	2·80	2·96
36	1·66	1·70	1·74	1·80	1·85	1·91	1·98	2·06	2·14	2·24	2·34	2·46	2·60	2·75
38	1·54	1·58	1·62	1·67	1·72	1·78	1·84	1·91	1·99	2·08	2·18	2·29	2·41	2·56
40	1·44	1·47	1·51	1·55	1·60	1·66	1·72	1·78	1·85	1·94	2·03	2·13	2·25	2·38
42	1·34	1·37	1·41	1·45	1·49	1·54	1·60	1·66	1·73	1·80	1·89	1·99	2·09	2·22
44	1·25	1·28	1·31	1·35	1·39	1·44	1·49	1·55	1·61	1·68	1·76	1·85	1·95	2·07
46	1·16	1·19	1·23	1·26	1·30	1·34	1·39	1·44	1·50	1·56	1·64	1·73	1·82	1·93
48	1·09	1·11	1·14	1·17	1·21	1·25	1·30	1·35	1·40	1·46	1·53	1·61	1·70	1·80
50	1·01	1·04	1·06	1·09	1·13	1·16	1·21	1·25	1·31	1·36	1·43	1·50	1·58	1·68
52	0·94	0·96	0·99	1·01	1·05	1·09	1·12	1·17	1·22	1·27	1·33	1·40	1·47	1·56
54	0·88	0·90	0·92	0·95	0·98	1·01	1·04	1·09	1·13	1·18	1·23	1·30	1·37	1·45
56	0·81	0·83	0·85	0·88	0·91	0·94	0·97	1·01	1·05	1·10	1·15	1·21	1·27	1·35
58	0·75	0·77	0·79	0·81	0·84	0·87	0·90	0·93	0·97	1·01	1·06	1·12	1·18	1·25
60	0·70	0·71	0·73	0·75	0·78	0·80	0·83	0·86	0·90	0·94	0·98	1·03	1·09	1·15
62	0·64	0·66	0·67	0·69	0·72	0·74	0·76	0·79	0·83	0·86	0·90	0·95	1·00	1·06
64	0·59	0·60	0·62	0·64	0·66	0·68	0·70	0·73	0·76	0·79	0·83	0·87	0·92	0·97
66	0·54	0·55	0·56	0·58	0·60	0·62	0·64	0·66	0·69	0·72	0·76	0·79	0·84	0·89
68	0·49	0·50	0·51	0·53	0·54	0·56	0·58	0·60	0·63	0·65	0·69	0·72	0·76	0·81
70	0·44	0·45	0·46	0·47	0·49	0·51	0·52	0·54	0·57	0·59	0·62	0·65	0·68	0·73
72	0·39	0·40	0·41	0·42	0·44	0·45	0·47	0·49	0·51	0·53	0·55	0·58	0·61	0·65
74	0·34	0·36	0·36	0·37	0·38	0·40	0·41	0·43	0·44	0·46	0·49	0·52	0·54	0·57
76	0·30	0·31	0·31	1·32	0·33	0·34	0·36	0·37	0·39	0·40	0·42	0·45	0·47	0·50
78	0·25	0·26	0·27	0·28	0·29	0·29	0·30	0·32	0·33	0·34	0·36	0·38	0·40	0·42
80	0·21	0·22	0·22	0·23	0·24	0·24	0·25	0·26	0·27	0·29	0·30	0·31	0·33	0·35
82	0·17	0·17	0·18	0·18	0·19	0·19	0·20	0·21	0·22	0·23	0·24	0·25	0·26	0·28
84	0·13	0·13	0·13	0·14	0·14	0·14	0·15	0·16	0·16	0·17	0·18	0·19	0·20	0·21
86	0·08	0·08	0·09	0·09	0·09	0·10	0·10	0·10	0·11	0·11	0·12	0·12	0·13	0·14
88	0·04	0·04	0·04	0·04	0·05	0·05	0·05	0·05	0·05	0·06	0·06	0·06	0·07	0·07
89	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·03	0·03	0·03	0·03	0·04	0·05	0·05
90	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00

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TABLE II.

Showing the error in the Longitude produced by an error of 1′ in the Altitude.

True Bearing.	LATITUDE.																		
	4°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	38°	40°	42°
10°	5′77	5′82	5′85	5′89	5′93	5′99	6′06	6′13	6′21	6′30	6′41	6′52	6′65	6′79	6′95	7′12	7′31	7′52	7′75
12	4·82	4·86	4·88	4·92	4·96	5·00	5·06	5·12	5·19	5·27	5·35	5·45	5·55	5·67	5·80	5·95	6·10	6·28	6·47
14	4·14	4·17	4·20	4·23	4·26	4·30	4·35	4·40	4·46	4·53	4·60	4·68	4·77	4·87	4·99	5·11	5·25	5·40	[illegible]
16	3·64	3·66	3·68	3·71	3·74	3·77	3·81	3·86	3·91	3·97	4·04	4·11	4·19	4·28	4·38	4·49	4·60	4·74	4·88
18	3·24	3·27	3·29	3·31	3·34	3·37	3·40	3·44	3·49	3·54	3·60	3·67	3·74	3·82	3·90	4·00	4·11	4·22	4·39
20	2·93	2·95	2·97	2·99	3·01	3·04	3·07	3·11	3·15	3·20	3·25	3·31	3·38	3·45	3·53	3·61	3·71	3·82	3·93
22	2·68	2·70	2·71	2·73	2·75	2·78	2·81	2·84	2·88	2·92	2·97	3·03	3·09	3·15	3·22	3·30	3·39	3·49	[illegible]
24	2·47	2·48	2·50	2·52	2·54	2·56	2·59	2·62	2·65	2·69	2·74	2·79	2·84	2·90	2·97	3·04	3·12	3·21	3·31
26	2·29	2·30	2·31	2·33	2·35	2·37	2·40	2·43	2·46	2·50	2·54	2·58	2·63	2·69	2·75	2·82	2·89	2·98	3·07
28	2·14	2·15	2·16	2·18	2·20	2·22	2·24	2·27	2·30	2·33	2·37	2·41	2·46	2·51	2·57	2·63	2·70	2·78	2·87
30	2·01	2·02	2·03	2·04	2·06	2·08	2·10	2·13	2·16	2·19	2·23	2·27	2·31	2·36	2·41	2·47	2·54	2·61	[illegible]
32	1·89	1·91	1·92	1·93	1·94	1·96	1·98	2·01	2·04	2·07	2·10	2·14	2·18	2·23	2·28	2·33	2·39	2·46	2·54
34	1·79	1·81	1·82	1·83	1·84	1·86	1·88	1·90	1·93	1·96	1·99	2·02	2·06	2·11	2·16	2·21	2·27	2·33	2·41
36	1·71	1·72	1·73	1·74	1·75	1·77	1·79	1·81	1·83	1·86	1·89	1·93	1·97	2·01	2·05	2·10	2·16	2·22	[illegible]
38	1·63	1·64	1·65	1·66	1·67	1·69	1·71	1·73	1·75	1·78	1·81	1·84	1·88	1·92	1·96	2·01	2·06	2·12	2·19
40	1·56	1·57	1·58	1·59	1·60	1·62	1·64	1·66	1·68	1·70	1·73	1·76	1·80	1·84	1·88	1·92	1·97	2·03	2·09
42	1·50	1·51	1·52	1·53	1·54	1·55	1·57	1·59	1·61	1·63	1·66	1·69	1·72	1·76	1·80	1·85	1·90	1·95	2·01
44	1·44	1·45	1·46	1·47	1·48	1·49	1·51	1·53	1·55	1·57	1·60	1·63	1·66	1·70	1·74	1·78	1·83	1·88	1·94
46	1·39	1·40	1·41	1·42	1·43	1·44	1·46	1·48	1·50	1·52	1·55	1·58	1·61	1·64	1·68	1·72	1·76	1·81	1·87
48	1·35	1·36	1·37	1·38	1·39	1·40	1·41	1·43	1·45	1·47	1·49	1·52	1·55	1·58	1·62	1·66	1·71	1·76	1·81
50	1·31	1·32	1·33	1·34	1·35	1·36	1·37	1·39	1·41	1·43	1·45	1·48	1·51	1·54	1·57	1·61	1·66	1·71	1·76
52	1·27	1·28	1·29	1·30	1·31	1·32	1·33	1·35	1·37	1·39	1·41	1·44	1·47	1·50	1·53	1·57	1·61	1·66	1·71
54	1·24	1·25	1·25	1·26	1·27	1·28	1·30	1·32	1·34	1·36	1·38	1·40	1·43	1·46	1·49	1·53	1·57	1·61	1·66
56	1·21	1·22	1·22	1·23	1·24	1·25	1·26	1·28	1·30	1·32	1·34	1·36	1·39	1·42	1·45	1·49	1·53	1·57	1·62
58	1·18	1·19	1·20	1·21	1·22	1·23	1·24	1·25	1·27	1·29	1·31	1·33	1·36	1·39	1·42	1·46	1·50	1·54	1·59
60	1·16	1·17	1·18	1·19	1·20	1·21	1·22	1·23	1·25	1·27	1·29	1·31	1·34	1·37	1·40	1·43	1·47	1·51	[illegible]
62	1·14	1·14	1·15	1·16	1·17	1·18	1·19	1·20	1·22	1·24	1·26	1·28	1·31	1·34	1·37	1·40	1·44	1·48	1·52
64	1·12	1·12	1·13	1·14	1·15	1·16	1·17	1·18	1·20	1·22	1,24	1·26	1·28	1·31	1·34	1·37	1·41	1·45	[illegible]
66	1·10	1·11	1·11	1·12	1·13	1·14	1·15	1·16	1·18	1·20	1·22	1·24	1·26	1·29	1·32	1·35	1·39	1·43	1·47
68	1·08	1·09	1·09	1·10	1·11	1·12	1·13	1·14	1·16	1·18	1·20	1·22	1·24	1·27	1·30	1·33	1·37	1·41	1·45
70	1·07	1·07	1·08	1·09	1·10	1·11	1·12	1·13	1·15	1·17	1·19	1·21	1·23	1·25	1·28	1·31	1·35	1·39	[illegible]
72	1·05	1·06	1·07	1·07	1·08	1·09	1·11	1·12	1·13	1·15	1·17	1·19	1·21	1·24	1·27	1·30	1·33	1·37	1·41
74	1·04	1·05	1·06	1·06	1·07	1·08	1·09	1·10	1·12	1·14	1·16	1·18	1·20	1·23	1·26	1·29	1·32	1·36	1·40
76	1·03	1·04	1·05	1·05	1·06	1·07	1·08	1·09	1·11	1·13	1·15	1·17	1·19	1·21	1·24	1·27	1·31	1·35	[illegible]
78	1·02	1·03	1·04	1·04	1·05	1·06	1·07	1·09	1·10	1·12	1·14	1·16	1·18	1·20	1·23	1·26	1·29	1·33	[illegible]
80	1·02	1·02	1·03	1·04	1·05	1·06	1·07	1·08	1·09	1·11	1·13	1·15	1·17	1·19	1·22	1·25	1·29	1·33	1·37
82	1·01	1·02	1·03	1·03	1·04	1·05	1·06	1·07	1·09	1·11	1·13	1·15	1·17	1·19	1·22	1·25	1·28	1·32	1·36
84	1·01	1·02	1·02	1·03	1·04	1·05	1·06	1·07	1·08	1·10	1·12	1·14	1·16	1·18	1·21	1·24	1·27	1·31	1·35
86	1·00	1·01	1·02	1·02	1·03	1·04	1·05	1·06	1·08	1·10	1·12	1·14	1·16	1·18	1·21	1·24	1·27	1·31	1·35
88	1·00	1·01	1·02	1·02	1·03	1·04	1·05	1·06	1·08	1·10	1·11	1·13	1·15	1·18	1·21	1·24	1·27	1·31	1·35
89	1·00	1·01	1·01	1·02	1·03	1·04	1·05	1·06	1·08	1·09	1·11	1·13	1·15	1·18	1·21	1·24	1·27	1·31	1·35
90	1·00	1·01	1·01	1·02	1·03	1·04	1·05	1·06	1·08	1·09	1·11	1·13	1·15	1·18	1·21	1·24	1·27	1·31	1·35

TABLE II.

Showing the error in the Longitude produced by an error of 1′ in the Altitude.

True Bearing.	LATITUDE.																		
	44°	46°	48°	50°	52°	54°	56°	58°	60°	62°	64°	66°	68°	70°	72°	74°	76°	78°	80°
10°	8′·01	8′·29	8′·61	8′·96	9′·35	9′·80	10′·30	10′·87	11′·52	12′·27	13′·14	14′·16	15′·37	16′·84	18′·64	20′·89	23′·80	27′·70	33′·16
12	6·69	6·92	7·19	7·48	7·81	8·18	8·60	9·08	9·62	10·24	10·97	11·83	12·84	14·06	15·56	17·45	19·88	23·13	27·70
14	5·75	5·95	6·18	6·43	6·71	7·03	7·39	7·80	8·27	8·81	9·43	10·16	11·05	12·09	13·38	15·00	17·09	19·88	23·80
16	5·04	5·22	5·42	5·64	5·89	6·17	6·49	6·85	7·26	7·73	8·28	8·92	9·69	10·61	11·74	13·16	15·00	17·45	20·89
18	4·50	4·66	4·84	5·03	5·26	5·51	5·79	6·11	6·47	6·89	7·38	7·96	8·64	9·46	10·47	11·74	13·38	15·56	18·64
20	4·06	4·21	4·37	4·55	4·75	4·97	5·23	5·52	5·85	6·23	6·67	7·19	7·81	8·55	9·46	10·61	12·09	14·06	16·84
22	3·71	3·84	3·98	4·15	4·33	4·54	4·78	5·04	5·34	5·68	6·10	6·57	7·12	7·80	8·63	9·70	11·03	12·85	15·37
24	3·42	3·54	3·67	3·83	4·00	4·18	4·40	4·64	4·92	5·24	5·62	6·05	6·57	7·20	7·97	8·93	10·17	11·85	14·15
26	3·17	3·29	3·41	3·55	3·70	3·88	4·08	4·30	4·56	4·86	5·20	5·61	6·09	3·67	7·38	8·27	9·43	10·95	13·15
28	2·96	3·07	3·19	3·32	3·46	3·62	3·81	4·02	4·26	4·54	4·86	5·23	5·67	6·23	6·90	7·73	8·80	10·25	12·25
30	2·78	2·88	2·99	3·11	3·25	3·41	3·58	3·78	4·00	4·26	4·56	4·92	5·33	5·85	6·47	7·27	8·27	9·66	11·50
32	2·62	2·72	2·82	2·94	3·06	3·21	3·37	3·56	3·77	4·01	4·31	4·64	5·04	5·52	6·09	6·86	7·79	9·09	10·87
34	2·49	2·57	2·67	2·78	2·90	3·04	3·20	3·38	3·58	3·82	4·08	4·40	4·77	5·23	5·79	6·49	7·39	8·59	10·26
36	2·37	2·45	2·54	2·65	2·77	2·90	3·04	3·20	3·40	3·63	3·88	4·18	4·54	4·97	5·51	6·17	7·04	8·21	9·81
38	2·26	2·34	2·43	2·53	2·64	2·76	2·91	3·07	3·25	3·46	3·71	3·99	4·34	4·75	5·25	5·88	6·71	7·82	9·37
40	2·16	2·24	2·33	2·42	2·53	2·65	2·78	2·93	3·11	3·31	3·55	3·82	4·15	4·55	5·03	5·64	6·43	7·48	8·96
42	2·08	2·15	2·23	2·32	2·43	2·54	2·67	2·82	2·99	3·18	3·41	3·68	3·98	4·38	4·85	5·41	6·17	7·17	8·63
44	2·00	2·07	2·15	2·24	2·34	2·45	2·58	2·72	2·88	3·06	3·28	3·55	3·85	4·20	4·67	5·23	5·95	6·93	8·30
46	1·93	2·00	2·08	2·16	2·26	2·37	2·49	2·62	2·78	2·96	3·18	3·43	3·71	4·07	4·50	5·04	5·75	6·70	8·00
48	1·87	1·94	2·01	2·09	2·18	2·29	2·41	2·54	2·69	2·87	3·07	3·31	3·59	3·94	4·35	4·89	5·58	6·48	7·77
50	1·82	1·88	1·95	2·03	2·12	2·22	2·33	2·46	2·61	2·78	2·98	3·21	3·49	3·82	4·22	4·73	5·37	6·27	7·53
52	1·77	1·83	1·90	1·98	2·06	2·16	2·27	2·39	2·54	2·71	2·90	3·12	3·39	3·71	4·10	4·60	5·25	6·10	7·30
54	1·72	1·78	1·85	1·92	2·01	2·10	2·21	2·33	2·47	2·63	2·82	3·04	3·30	3·61	3·99	4·49	5·12	5·93	7·13
56	1·68	1·74	1·80	1·88	1·96	2·05	2·16	2·28	2·41	2·57	2·75	2·97	3·22	3·52	3·89	4·37	4·97	5·77	6·93
58	1·64	1·70	1·76	1·83	1·91	2·00	2·11	2·23	2·36	2·51	2·69	2·90	3·15	3·45	3·84	4·28	4·86	5·66	6·79
60	1·61	1·67	1·73	1·80	1·88	1·97	2·07	2·19	2·32	2·47	2·64	2·85	3·10	3·40	3·76	4·20	4·77	5·57	6·66
62	1·57	1·63	1·69	1·76	1·84	1·93	2·03	2·14	2·26	2·41	2·58	2·78	3·02	3·31	3·67	4·11	4·67	5·46	6·51
64	1·55	1·60	1·66	1·73	1·81	1·89	1·99	2·10	2·22	2·37	2·54	2·74	2·97	3·25	3·61	4·04	4·61	5·36	6·41
66	1·52	1·57	1·63	1·70	1·78	1·86	1·96	2·07	2·19	2·33	2·50	2·69	2·92	3·20	3·54	3·97	4·51	5·27	6·31
68	1·50	1·55	1·61	1·68	1·75	1·83	1·93	2·04	2·16	2·30	2·46	2·65	2·88	3·16	3·50	3·93	4·46	5·20	6·20
70	1·48	1·53	1·59	1·66	1·73	1·81	1·90	2·01	2·13	2·27	2·43	2·62	2·84	3·11	3·45	3·86	4·41	5·11	6·12
72	1·46	1·51	1·57	1·64	1·71	1·79	1·88	1·98	2·10	2·24	2·40	2·59	2·81	3·07	3·40	3·81	4·35	5·05	6·06
74	1·45	1·50	1·56	1·62	1·69	1·77	1·86	1·96	2·08	2·22	2·37	2·56	2·78	3·03	3·37	3·77	4·30	5·00	6·00
76	1·43	1·48	1·54	1·60	1·67	1·75	1·84	1·94	2·06	2·20	2·35	2·54	2·75	3·01	3·34	3·74	4·25	4·95	5·94
78	1·42	1·47	1·53	1·59	1·66	1·74	1·83	1·93	2·04	2·18	2·33	2·51	2·73	2·99	3·31	3·71	4·21	4·91	5·90
80	1·41	1·46	1·52	1·58	1·65	1·73	1·82	1·92	2·03	2·16	2·32	2·50	2·71	2·97	3·28	3·68	4·18	4·88	5·85
82	1·40	1·45	1·51	1·57	1·64	1·72	1·81	1·91	2·02	2·15	2·30	2·48	2·70	2·95	3·27	3·67	4·17	4·85	5·81
84	1·40	1·45	1·50	1·56	1·63	1·71	1·80	1·90	2·01	2·14	2·29	2·47	2·68	2·94	3·25	3·65	4·16	4·83	5·79
86	1·39	1·44	1·50	1·56	1·63	1·71	1·79	1·89	2·00	2·14	2·29	2·46	2·67	2·93	3·24	3·64	4·14	4·81	5·77
88	1·39	1·44	1·50	1·56	1·63	1·70	1·79	1·89	2·00	2·13	2·28	2·46	2·67	2·93	3·24	3·64	4·14	4·80	5·76
89	1·39	1·44	1·49	1·55	1·62	1·70	1·79	1·89	2·00	2·13	2·28	2·46	2·67	2·92	3·23	3·63	4·13	4·80	5·76
90	1·39	1·44	1·49	1·55	1·62	1·70	1·79	1·89	2·00	2·13	2·28	2·46	2·67	2·92	3·23	3·63	4·13	4·80	5·76

paratively rude nature of the observation, and in consequence thrown away.

Equation of Time—*when* to apply it.

Usually, the Equation of Time is applied to the Apparent Time 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.

About as good a way as any for finding the time at ship is Method I. of Norie, which will accordingly be here used in the examples.

Delusive "short methods."

It is necessary to beware of those 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.

Martelli's short method.

As a case in point we will take the small but expensive pamphlet by Mr. Martelli, which contains rules and tables for finding the longitude by chronometer.

When his so-called "short method" is properly overhauled and compared with Norie's Method I., we get the following startling result:—Martelli, 56 figures and 5 logarithms, against Norie'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, Mr. Martelli's pamphlet contains several glaring errors which make one rather dubious about the general correctness of the tables, although (for all the writer knows to the contrary) the mathematical principle of his method may be correct enough.

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. ☉ 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. 00s. 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° 00′ N., and Long. 57° 12′ W., both by dead reckoning. Required the longitude. **Example shewing advantage of observations on Prime Vertical.**

```
                               H. M. S.          °  ′                       s.
Time by chronometer  - -       7 43 57       ☉  37 49¾                 0·52 hourly diff.
Slow  - - - - - - - - -      + 4 00           +  9   Table IX.        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 37¼      Cosecant - 0·03720
Latitude  - - -    40 00       Secant - - 0·11575
Altitude  - - -    37 58¾      Cosine - - 9·48292
                  -------      Sine   - - 9·75114
                  144 36                  -------  H. M. S.
                  -------                 9·38701 = 8 56 42 Apparent Time at Ship.
½ sum  - - - -     72 18                  -------   7 45 27   ,,     ,,    Greenwich.
Remainder  - -     34 19¼                           -------
                  =======      Longitude in time -  8 48 45 = 57° 11¼′ W.
                                                    =======
```

Same sight worked with latitude 39° 20′ N., or 40′ in error.

```
  P.D.   66° 37¼′       0·03720
  Lat.   39  20         0·11156
  Alt.   37  58¾        9·49076
        --------        9·74742
        143  56        --------    H.  M.  S.
        --------        9·38694 =  8  56  41   App. Time at Ship.
½ Sum.   71  58                    7  45  27     ,,     ,,     Greenwich.
  Rem.   33  59¼                  ----------
                                   8  48  46 = 57° 11½′ 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 0¼′.

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. should occasionally be consulted, to see if either of these planets are available. Their Right Ascensions **Venus or Jupiter for latitude, simultaneous with sun for longitude.**

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.

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., and 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 234).

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 ..	8 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. .. .. ×	8·75
	3520
	4928
	2112
	24)2640″·00(110″=1′ 50″
	24
	24
	24

	° ′ ″
Declin. of Venus June 15th..	23 8 39 N.
Decrease in 8hrs. 45m. .. .. −	1 50
Declin. corrected for G.M.T.	23° 6′ 49″ N.
	° ′
Obs. alt. of Venus	64 38½
Corr. Table XV. of Norie .. −	5
True alt.	64 33½
	90
Merid. zen. dist.	25 26½ N.
Corrected declin.	23 6¾ N.
Latitude	48° 33′ N.

Now, the apparent 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 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 461 of the N.A. for 1884, under the heading of PHENOMENA, this is shewn to occur on August 17th.

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 the 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 anything strikingly different to what is contained in the examples

* Raper.

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 228.

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. 86½ W. "	" "

Position by account, Lat. 43° 20′ N. Longitude 43° 24′ W. No index error. Chron. slow of G.M.T. 4m. 00s. 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 XV. of *Norie*	− 8¼
*'s true altitude	14 35¼

	° ′		
	90		
*'s Declination	8 33¼ N.		
*'s Polar distance	81 26¾	Cosecant	0·00486
Ship's latitude	43 24¼	Secant	0·13878
*'s altitude	14 35¼	Cosine	9·53982
		Sine	9·91407
	139 26¼		
			9·59753
Half sum	69 43⅛		
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 04¼	0·14362
14 35¼	9·53292
	9·91582
140 6¼	
	9·59722
70 3⅛	
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 18¼
Table XV. of Norie	− 7¾
✱'s true alt.	22°10½′

	° ′		
	90		
✱'s Declination	12 33 N.		
✱'s Polar distance	77 27	.... Cosecant	0·01050
Ship's latitude	43 23½	.... Secant	0·13363
✱'s altitude	22 10½		
	143 01		
Half sum	71 30½	Cosine	9·50129
Remainder	49 19¾	Sine	9·87994
			9·53036

	H. M. S.	
✱'s Hour angle	4 44 56 W.	= true azimuth, S. 86½ 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 29½ W.
Correction for run between sights		− 3
Longitude corresponding to that by Altair		43° 26½′ W.

SAME SIGHT WORKED WITH LATITUDE 40′ IN ERROR.

° ′	
77 27	0·01050
44 3½	0·14846
22 10½	9·49366
	9·88210
143 41	
	9·52972
71 50½	
49 39½	H. M. S.
	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 0¾′, 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." Practice 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; but Mr. A. C. JOHNSON, in his valuable pamphlet already alluded to, shews how the sights can *at once* be worked out in full with the latitude *by account*, and *afterwards* corrected by Table I. 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
Slow	+ 4 3
	1 22 40
Corrected Equation of Time..	— 4 42
Greenwich Apparent Time ..	1 17 58

Observed altitude .. ⊙	56° 44¼′
	+ 10
⊙	56° 54¼′

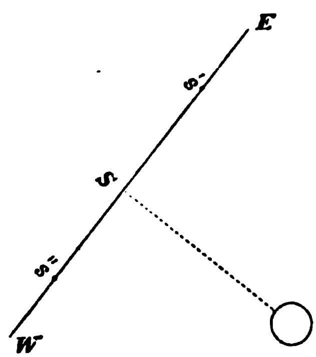
	° ′		
	90		
Corrected declination ..	22 31¾		
P. D.	67 28¼	Cosecant	0·03447
Latitude by account	39 51¼	Secant	0·11482
Altitude	56 54¼	Cosine	9·13722
		Sine	9·62932
	164 14		
			8·91583
Half sum.. ..	82 7		
Remainder ..	25 12¾		

	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° 51¼′ 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 I., the error of longitude due to an error of 1′ in the latitude is 0′·52, which, multiplied by 10′·2, gives 5¼′, to be applied as a correction to the above longitude. We have, therefore, for the true position at noon, latitude 39° 41′ N., and longitude 52° 21¾′ W.

Johnson's rule for applying the correction.

Johnson gives 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:—



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.

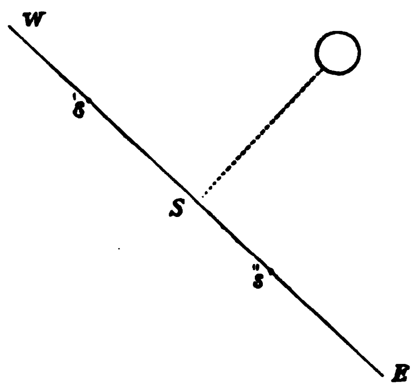
Method used by writer for same purpose.

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,

* See page 324.

say at s″, then the longitude is thrown to the westward. This can easily be done mentally. The plan holds good for a bearing in any quadrant of the compass.

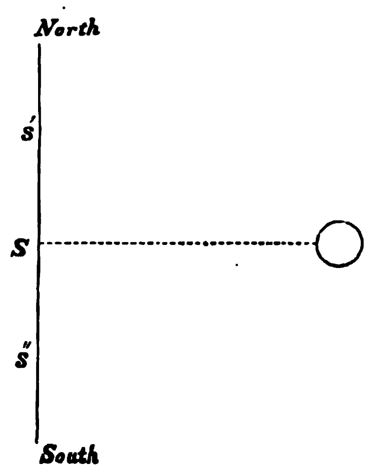
Let us suppose another case, where the celestial object bears N.E. Then the imaginary line would run N.W. and S.E., thus:—



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.* 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?

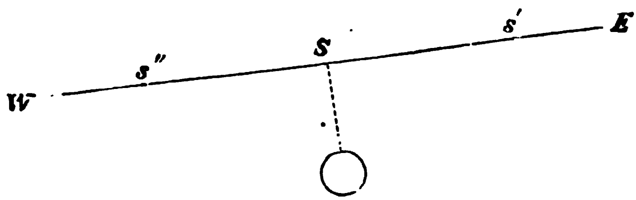


Diagram shewing disadvantage of observs. for time near the meridian.

It will now be evident that a small error in the latitude will produce a very large one in the longitude; *shewing the impropriety of taking sights for Time when the bearing of the object is near the North or South points.*

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.

Proper way of looking at a chart.

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 is not to be recommended, and conveys an unstable idea of geographical position.

SHORT EQUAL ALTITUDES.

Equal altitudes at sea.

There is one other mode of finding the longitude by chronometer, which, from its extreme simplicity and the few figures required, is very alluring. Unfortunately for everyone, it is restricted in its application, and the results cannot be depended upon as more than roughly approximate. The method referred to is that of Equal Altitudes taken a few minutes before and after noon.

If the course in the interval be east or west, or the vessel be stationary, and the altitude not under 75°, the longitude will probably be somewhere near the truth, so that sailing ships lying becalmed near the line may find it convenient; but if the course be towards the north or south, and the vessel's speed at all considerable, there will be a large error due to the observer's change of latitude unless it is allowed for: this, however, is easily done as follows:—

Ascertain by the Traverse Tables the difference of latitude which will be made good between sights, and add this to, or subtract it from, the observed forenoon altitude, according as to whether the ship has sailed towards or from the sun in the interval. Set the sextant to this corrected altitude, and, when the sun falls to it, note the chronometer time.

Should the celestial object be the sun, an altitude sufficiently great cannot be obtained in high latitudes, and in low ones there are generally better modes available. If the quantities in Table II, (pages 290, 291), be multiplied by 4, so as to convert them into seconds of time, it will be seen that, even in moderately high latitudes, the change of altitude near noon is very slow. Inversely, an error of even 1′ in the altitude 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. 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.

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., corrected as above for difference of latitude made good in the interval, 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, accord-

ing 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.

Example I.

Ship stationary, or steering either East or West (true).

August 3rd, 1881. Observed altitude, ☉ 80° in West Longitude.

	H. M. S.	
Time by chronometer	8 2 10	at A.M. altitude.
Time by chronometer	8 14 20	at P.M. altitude.
	6 16 30	
Middle time	8 8 15	
Chronom. slow of G.M.T. .. .. .. +	4 17	
Greenwich Mean Time	8 12 32	
Corrected Equation of Time .. .. –	5 55	Page II., N.A.
	H. M. S.	
Longitude in time	8 6 37	= 46° 39¼′ W. at Noon.

Example II.

Where ship has changed her Latitude between sights.

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° 00′ (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 knots, the sun was observed to be approaching the same altitude. After taking out the difference of latitude (5′) due to this course and distance, the Sextant was set to 76° 5′, and when the ☉ had dropped to this altitude the same chronometer shewed 9h. 1m. 18s. Required the latitude and longitude at noon.

Note:—As the ship had been sailing *towards* the sun in the interval between sights, the difference of latitude made good had to be *added* to the first or forenoon altitude.

	H.	M.	S.	
Time by chronometer at A.M. observation ..	8	30	42	.. .. ☉ 76° 0′
Time by chronometer at P.M. " ..	9	01	18	.. .. ☉ 76° 5′
	17	32	00	
Middle time by chronometer	8	46	00	
Chronometer fast of G.M.T. .. .. –		10	20	
Greenwich Mean Time	8	35	40	
Corrected Equation of Time .. .. –		5	56	Page II., N.A.
Greenwich Apparent Time	8	29	44	
Apparent Time at Ship = noon, or	12	00	00	Corresponding to middle time by chronometer.
	H.	M.	S.	
Longitude in time..	3	30	16	= 52° 34′ East 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.*

In sight-taking, should an assistant not be available to note the chronometer time, the 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.*