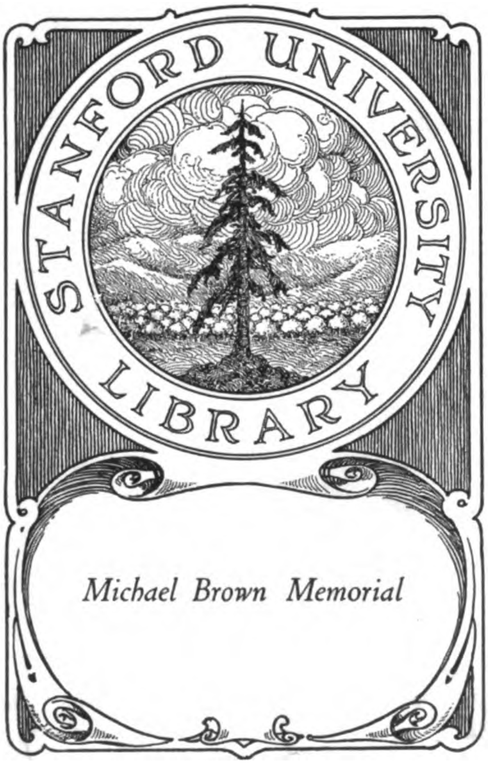
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No. 9

American Practical Navigator

An Epitome of Navigation and Nautical Astronomy

ORIGINALLY BY
NATHANIEL BOWDITCH, LL. D.

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STATUTES OF AUTHORIZATION.

There shall be a Hydrographic Office attached to the Bureau of Navigation in the Navy Department, for the improvement of the means for navigating safely the vessels of the Navy and of the mercantile marine, by providing, under the authority of the Secretary of the Navy, accurate and cheap nautical charts, sailing directions, navigators, and manuals of instructions for the use of all vessels of the United States, and for the benefit and use of navigators generally. (R. S. 431.)

The Secretary of the Navy is authorized to cause to be prepared, at the Hydrographic Office attached to the Bureau of Navigation in the Navy Department, maps, charts, and nautical books relating to and required in navigation, and to publish and furnish them to navigators at the cost of printing and paper, and to purchase the plates and copyrights of such existing maps, charts, navigators, sailing directions, and instructions, as he may consider necessary, and when he may deem it expedient to do so, and under such regulations and instructions as he may prescribe. (R. S. 432.)

PART I.

TEXT AND APPENDICES.

Note on Reprint of 1919.—All typographical or other errors, so far discovered, have been corrected in this edition. There has been introduced at the foot of Table 2 a panel of headings, enabling the user to see at a glance the interchanges of the designations of the different columns of the table in order to subserve the various uses for which it is adapted in Plane, Middle Latitude, and Mercator Sailing, and in the general solution of plane right-angled triangles.

Article 274, on the subject of Mean Time, and article 332, on the subject of finding the Latitude by a single Altitude at a given time, have been revised.

The Knot as a measure of speed has been defined in article 10, and Leeway has been defined in a footnote to page 84.

The application of the Haversine table, No. 45, to the solution of the Time Sight has been explained in articles 319 and 343, and to the solution of Altitude-Azimuth in article 355.

Misunderstandings having arisen regarding the paging of this book, the reader is advised that the consecutive page numbering is purposely interrupted as follows: Part I ends with page 387 and Part II begins with 501, no text or tables being omitted thereby. Page 531 is left blank to make better openings for Table 2. The blank page preceding 621 is likewise not an omission. Pages 734 to 738 were formerly taken up with Tables 37 and 37A (see p. 503).

CONTENTS OF PART I.

ABBREVIATIONS USED IN THIS WORK.

Alt. (or *h*)	Altitude.
a. m	Ante meridian.
Amp	Amplitude.
App	Apparent.
App. t	Apparent time.
Ast	Astronomical.
Ast. t	Astronomical time.
Aug	Augmentation.
Az. (or Z)	Azimuth.
C	Course.
C. C	Chronometer correction.
C—W	Chronometer *minus* watch.
Chro. t	Chronometer time.
Co. L	Co. latitude.
Col	Column.
Corr	Correction.
Cos	Cosine.
Cosec	Cosecant.
Cot	Cotangent.
d (or Dec.)	Declination.
D (or D.Lo)	Difference longitude.
Dep	Departure.
Dev	Deviation.
Diff	Difference.
Dist	Distance.
DL	Difference latitude.
D. R	Dead reckoning.
E., Ely	East, easterly.
Elap. t	Elapsed time.
Eq. t	Equation of time.
F	Longitude factor.
f	Latitude factor.
G. (or Gr.)	Greenwich.
G. A. T	Greenwich apparent time.
G. M. T	Greenwich mean time.
G. S. T	Greenwich sidereal time.
h	Altitude.
H	Meridian altitude.
H. A. (or *t*)	Hour angle.
Hav	Haversine.
H. D	Hourly difference.
H. P. (or Hor. par.)	Horizontal parallax.
Hr-s	Hour-s.
H. W	High water.
I. C	Index correction.
L. (or Lat.)	Latitude.
L. A. T	Local apparent time.
L. M. T	Local mean time.
L. S. T	Local sidereal time.
Lo. (or Long.)	Longitude.
Log	Logarithm.
Lun. Int	Lunitidal interval.
L. W	Low water.
λ	Longitude.
m	Meridional difference.
Merid	Meridian or noon.
Mag	Magnetic.
M. D	Minute's difference.
Mid	Middle.
Mid. L	Middle latitude.
M. T	Mean time.
nat	Natural.
N., Nly	North, northerly.
N. A. (or Naut. Alm.)	Nautical Almanac.
Np	Neap.
Obs	Observation.
p (or P. D.)	Polar distance.
p. c	Per compass.
P. D. (or *p*)	Polar distance.
P. L. (or Prop. Log.)	Proportional logarithm.
p. m	Post meridian.
p. & r	Parallax and refraction.
Par	Parallax.
R. A	Right ascension.
R. A. M. S	Right ascension mean sun.
Red	Reduction.
Ref	Refraction.
S., Sly	South, southerly.
S. D	Semidiameter.
Sec	Secant.
Sid	Sidereal.
Sin	Sine.
Spg	Spring.
t	Hour angle.
T	Time.
Tab	Table.
Tan	Tangent.
Tr. (or Trans.)	Transit.
Var	Variation.
Vert	Vertex or vertical.
W., Wly	West, westerly.
W. T	Watch time.
z	Zenith distance.
Z	Azimuth.
θ	Auxiliary angle.
λ	Difference longitude in time.

SYMBOLS.

☉	The Sun.
☾	The Moon.
✳	A Star or Planet.
$\overline{☉}$ $\overline{☾}$	Alt. upper limb.
$\underline{☉}$ $\underline{☾}$	Alt. lower limb.
⏀ ⏀	Azimuthal angle.
°	Degrees.
′	Minutes of Arc.
″	Seconds of Arc.
h	Hours.
m	Minutes of Time.
s	Seconds of Time.

GREEK LETTERS.

Α α	Alpha.
Β β	Beta.
Γ γ	Gamma.
Δ δ	Delta.
Ε ε	Epsilon.
Ζ ζ	Zeta.
Η η	Eta.
Θ θ	Theta.
Ι ι	Iota.
Κ κ	Kappa.
Λ λ	Lambda.
Μ μ	Mu.
Ν ν	Nu.
Ξ ξ	Xi.
Ο ο	Omicron.
Π π	Pi.
Ρ ρ	Rho.
Σ σ (ς)	Sigma.
Τ τ	Tau.
Υ υ	Upsilon.
Φ φ	Phi.
Χ χ	Chi.
Ψ ψ	Psi.
Ω ω	Omega.

CHAPTER I.

DEFINITIONS RELATING TO NAVIGATION.

1. That science, generally termed *Navigation*, which affords the knowledge necessary to conduct a ship from point to point upon the earth, enabling the mariner to determine, with a sufficient degree of accuracy, the position of his vessel at any time, is properly divided into two branches: *Navigation* and *Nautical Astronomy*.

2. *Navigation*, in its limited sense, is that branch which treats of the determination of the position of the ship by reference to the earth, or to objects thereon. It comprises (*a*) *Piloting*, in which the position is ascertained from visible objects upon the earth, or from soundings of the depth of the sea, and (*b*) *Dead Reckoning*, in which the position at any moment is deduced from the direction and amount of a vessel's progress from a known point of departure.

3. *Nautical Astronomy* is that branch of the science which treats of the determination of the vessel's place by the aid of celestial objects—the sun, moon, planets, or stars.

4. Navigation and Nautical Astronomy have been respectively termed *Geo-Navigation* and *Celo-Navigation*, to indicate the processes upon which they depend.

5. As the method of piloting can not be employed excepting near land or in moderate depths of water, the navigator at sea must fix his position either *by dead reckoning* or *by observation of celestial objects;* the latter method is more exact, but as it is not always available, the former must often be depended upon.

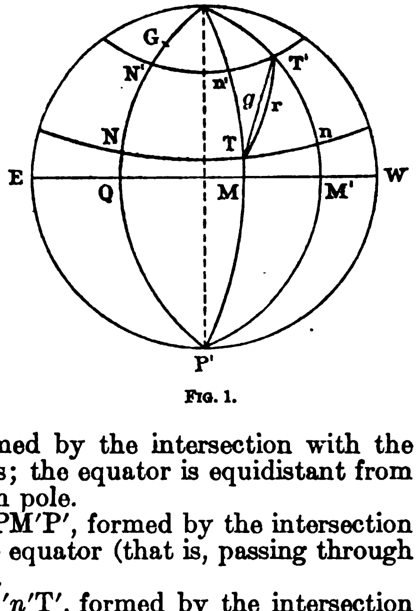

FIG. 1.

6. THE EARTH.—The Earth is an oblate spheroid, being a nearly spherical body slightly flattened at the poles; its longer or equatorial axis measures about 7,927 statute miles, and its shorter axis, around which it rotates, about 7,900 statute miles.

The Earth (assumed for purposes of illustration to be a sphere) is represented in figure 1.

The *Axis of Rotation*, usually spoken of simply as the *Axis*, is PP′.

The *Poles* are the points, P and P′, in which the axis intersects the surface, and are designated, respectively, as the *North Pole* and the *South Pole*.

The *Equator* is the great circle EQMW, formed by the intersection with the earth's surface of a plane perpendicular to the axis; the equator is equidistant from the poles, every point upon it being 90° from each pole.

Meridians are the great circles PQP′, PMP′, PM′P′, formed by the intersection with the earth's surface of planes secondary to the equator (that is, passing through its poles and therefore perpendicular to its plane).

Parallels of Latitude are small circles NT*n*, N′*n*′T′, formed by the intersection with the earth's surface of planes passed parallel to the equator.

The *Latitude* of a place on the surface of the earth is the arc of the meridian intercepted between the equator and that place. Latitude is reckoned *North* and *South*, from the equator as an origin, through 90° to the poles; thus, the latitude of the point T is MT, north, and of the point T′, M′T′, north. The *Difference of Latitude* between any two places is the arc of a meridian intercepted between their parallels of latitude, and is called *North* or *South*, according to direction; thus, the difference of latitude between T and T′ is T*n*′ or T′*n*, north from T or south from T′.

The *Longitude* of a place on the surface of the earth is the arc of the equator intercepted between its meridian and that of some place from which the longitude is reckoned. Longitude is measured *East* or *West* through 180° from the meridian of a designated place, such meridian being termed the *Prime Meridian;* the prime meridian used by most nations, including the United States, is that of Greenwich, England. If, in the figure, the prime meridian be PGQP′, then the longitude of the point T is QM, east, and of T′, QM′, east. The *Difference of Longitude* between any two places is the arc of the equator intercepted between their meridians, and is called *East* or *West*, according to direction; thus, the difference of longitude between T and T′ is MM′, east from M or west from M′. The *Departure* is the linear distance, measured on a parallel of latitude, between two meridians; unlike the various quantities previously defined, departure is reckoned in miles; the departure between two meridians varies with the parallel of latitude upon which it is measured; thus, the departure between the meridians of T and T′ is the number of miles corresponding to the distance T*n* in the latitude of T, or to *n*′T′ in the latitude of T′.

The curved line which joins any two places on the earth's surface, cutting all the meridians at the same angle, is called the *Rhumb Line*, *Loxodromic Curve*, or *Equiangular Spiral.* In the figure this line is represented by T*r*T′. The constant angle which this line makes with the meridians is called the *Course;* and the length of the line between any two places is called the *Distance* between those places.

The mile employed by navigators is the *Nautical* or *Sea Mile.* This unit is defined in the United States of America as being 6,080.27 feet in length and equal to one-sixtieth part of a degree of a great circle of a sphere whose surface is equal in area to the area of the surface of the earth.

The nautical mile is not exactly the same in all countries, but, from the navigator's standpoint, the various lengths adopted do not differ materially.

Since latitude has been capable of easier and more accurate determination than longitude, it might naturally be expected that there exists an intimate relation between the nautical mile and the minute of latitude (or the length of that portion of a meridian which, if the earth were a perfect sphere, would subtend the angle of 1′ at the center); but because the earth is not a perfect sphere, the length of that portion of a meridian that subtends an angle of 1′ at the center of the earth varies slightly in length from the Equator to the poles, and consequently the relation between the nautical mile and the minute of latitude is not exactly invariable. The average length of one minute of curvature of the meridian is 1,852.201 meters, or 6,076.82 feet; and, accordingly, in France, Germany, and Austria, the nautical mile is taken to be 1,852 meters.

For purposes of navigation the nautical mile is assumed to be equal to a minute of latitude in all parts of the world; and, hence, when a vessel changes her position to the north or south by 1 nautical mile, it may always be considered that the latitude has changed 1′. Owing to the fact that the meridians converge toward the poles, the difference of longitude produced by a change of position of 1 mile to the east or west will vary with the latitude; thus, a departure of 1 mile will equal a difference of longitude of 1′ at the Equator, but of more than 1′ at any higher latitude, being in fact equal to 1′.1 of longitude in latitude 30° and to 2′ of longitude in latitude 60°.

In England the nautical mile, corresponding to the *Admiralty knot*, is regarded as having a length of 6,080 feet.

The statute mile of 5,280 feet, which is employed in land measurements, is commonly used in navigating river and lake vessels. This is notably the case on the Great Lakes of America, but with the recognition of the advantages to be gained by the practice of nautical astronomy in the navigation of these vessels, the use of the nautical mile is extending.

The *Great Circle Track* or *Course* between any two places is the route between those places along the circumference of the great circle which joins them. In the figure this line is represented by T*g*T′. From the properties of a great circle (which is a circle upon the earth's surface formed by the intersection of a plane passed through its center) the distance between two points measured on a great circle track is shorter than the distance upon any other line which joins them. Except when the two points are on the same meridian or when both lie upon the equator, the great circle track will always differ from the rhumb line, and the great circle track will intersect each intervening meridian at a different angle.

CHAPTER II.

INSTRUMENTS AND ACCESSORIES IN NAVIGATION.

DIVIDERS OR COMPASSES.

7. This instrument consists of two legs movable about a joint, so that the points at the extremities of the legs may be set at any required distance from each other. It is used to take and transfer distances and to describe arcs and circles. When used for the former purpose it is termed *dividers*, and the extremities of both legs are metal points; when used for describing arcs or circles, it is called a *compass*, and one of the metal points is replaced by a pencil or pen.

PARALLEL RULERS.

8. *Parallel rulers* are used for drawing lines parallel to each other in any direction, and are particularly useful in transferring the rhumb-line on the chart to the nearest compass-rose to ascertain the course, or to lay off bearings and courses.

PROTRACTOR.

9. This is an instrument used for the measurement of angles upon paper; there is a wide variation in the material, size, and shape in which it may be made. (For a description of the *Three Armed Protractor*, see art. 428, Chap. XVII.)

SPEED MEASUREMENT.

10. The speed of a ship is measured by different devices (see arts. 11 to 17). In navigation the unit of speed is the knot; "10 knots" means 10 nautical miles per hour, a term derived from the original use of the Chip Log.

THE CHIP LOG.

11. This device, for measuring the rate of sailing, consists of three parts; viz, the *log-chip*, the *log-line*, and the *log-glass*. A light substance thrown from the ship ceases to partake of the motion of the vessel as soon as it strikes the water, and will be left behind on the surface; after a certain interval, if the distance of the ship from this stationary object be measured, the approximate rate of sailing will be given. The *log-chip* is the float, the *log-line* is the measure of the distance, and the *log-glass* defines the interval of time.

The *log-chip* is a thin wooden quadrant of about 5 inches radius, loaded with lead on the circular edge sufficiently to make it float upright in the water. There is a hole in each corner of the log-chip, and the log-line is knotted in the one at the apex; at about 8 inches from the end there is seized a wooden socket; a piece of line of proper length, being knotted in the other holes, has seized into its bight a wooden peg to fit snugly into the socket before the log-chip is thrown; as soon as the line is checked this peg pulls out, thus allowing the log-chip to be hauled in with the least resistance.

The *log-line* is about 150 fathoms in length, one end made fast to the log-chip, the other to a reel upon which it is wound. At a distance of from 15 to 20 fathoms from the log-chip a prominent mark of red bunting about 6 inches long is placed to allow sufficient *stray line* for the log-chip to clear the vessel's eddy or wake. The rest of the line is spaced into equal lengths by pieces of fish-line thrust through the strands, each distinguished by a number of knots tied in it according to the numerical order of its place counted from the stray-line mark of red bunting; hence these spaces are called "knots." Their length must bear the same ratio to the nautical mile as the number of seconds in which the log-glass runs down bears to the number of seconds in one hour, or some multiple of it. Each space or knot is further subdivided into five equal lengths of two-tenths of a knot each, marked by pieces of white rag.

In the United States Navy all log-lines are marked for log-glasses of 28 seconds, for which the proportion is:

$$x: 6080 = 28: 3600,$$

x being the length of the knot.

Hence,

$$x = 47^{ft}.29, \text{ or } 47^{ft}\ 3^{in}.$$

The speed of the ship is expressed in knots and tenths of a knot.

The *log-glass* is a sand glass of the same shape and construction as the old hour-glass. Two glasses are used, one of 28 seconds and one of 14 seconds; the latter is employed when the ship is going at a high rate of speed, the number of knots indicated on a line marked for a 28-second glass being doubled to obtain the true rate of speed.

The log in all its parts should be frequently examined and adjusted; the peg must be found to fit sufficiently tight to keep the log-chip upright; the log-line shrinks and stretches and should often be verified; the log-glass should be compared with a watch. One end of the glass is stopped with a cork, by removing which the sand may be dried or its quantity corrected.

12. A *ground log* consists of an ordinary log-line, with a lead attached instead of a chip; in shoal water, where there are no well-defined objects available for fixing the position of the vessel and the course and speed are influenced by a tidal or other current, this log is sometimes used, its advantage being that the lead marks a stationary point to which motion may be referred, whereas the chip would drift with the stream. The speed, which is marked in the usual manner, is the speed over the ground, and the trend of the line gives the course actually made good by the vessel.

THE PATENT LOG.

13. This is a mechanical contrivance for registering the distance actually run by a vessel through the water. There are various types of patent logs, but for the most part they act upon the same principle, consisting of a registering device, a fly or rotator, and a log or towline; the rotator is a small spindle with a number of blades extending radially in such manner as to form a spiral, and, when drawn through the water in the direction of its axis, rotates about that axis after the manner of a screw propeller; the rotator is towed from the vessel by means of a log or towline from 30 to 100 fathoms in length, made fast at its apex, the line being of special make, so that the turns of the rotator are transmitted through it to the worm shaft of the register, to which the inboard end of the line is attached; the registering device is so constructed as to show upon a dial face the distance run, according to the number of turns of its worm shaft due to the motion of the rotator; the register is carried at some convenient point on the vessel's quarter; it is frequently found expedient to rig it out upon a small boom, so that the rotator will be towed clear of the wake.

14. Though not a perfect instrument, the patent log affords a means of determining the vessel's speed through the water. It will usually be found that the indications of the log are in error by a constant percentage, and the amount of this error should be determined by careful experiment and applied to all readings.

Various causes may operate to produce inaccuracy of working in the patent log, such as the bending of the blades of the rotator by accidental blows, fouling of the rotator by seaweed or refuse from the ship, or mechanical wear of parts of the register. The length of the towline has much to do with the working of the log, and by varying the length the indications of the instrument may sometimes be adjusted when the percentage of error is small; it is particularly important that the line shall not be too short. The readings of the patent log can not be depended upon for accuracy at low speeds, when the rotator does not tow horizontally, nor in a head or a following sea, when the effect depends upon the wave motion as well as upon the speed of the vessel.

15. Electrical registers for patent logs are in use, the distance recorded by the mechanical register being communicated electrically to some point of the vessel which is most convenient for the purposes of those charged with the navigation.

16. A number of instruments based upon different physical principles have been devised for recording the speed of a vessel through the water and have been used with varying degrees of success. Of these the hydraulic speed indicator, known as the Nicholson Ship Log, affords an instance.

17. The revolutions of the screw propeller afford in a steamer the most valuable means of determining a vessel's speed through the water. The number of revolutions per knot must be carefully determined for the vessel by experiment under varying conditions of speed, draft, and foulness of bottom.

THE LEAD.

18. This device, for ascertaining the depth of water, consists essentially of a suitably marked line, having a lead attached to one of its ends. It is an invaluable aid to the navigator in shallow water, particularly in thick or foggy weather, and is often of service when the vessel is out of sight of land.

Two leads are used for soundings—the *hand-lead*, weighing from 7 to 14 pounds, with a line marked to about 25 fathoms, and the *deep-sea lead*, weighing from 30 to 100 pounds, the line being 100 fathoms or upward in length.

Lines are generally marked as follows:

2 fathoms from the lead, with 2 strips of leather.
3 fathoms from the lead, with 3 strips of leather.
5 fathoms from the lead, with a white rag.
7 fathoms from the lead, with a red rag.
10 fathoms from the lead, with leather having a hole in it.
13 fathoms from the lead, same as at 3 fathoms.
15 fathoms from the lead, same as at 5 fathoms.
17 fathoms from the lead, same as at 7 fathoms.
20 fathoms from the lead, with 2 knots.
25 fathoms from the lead, with 1 knot.
30 fathoms from the lead, with 3 knots.
35 fathoms from the lead, with 1 knot.
40 fathoms from the lead, with 4 knots.
And so on.

Fathoms which correspond with the depths marked are called *marks;* the intermediate fathoms are called *deeps;* the only fractions of a fathom used are a half and a quarter.

A practice sometimes followed is to mark the hand-lead line in feet around the critical depths of the vessel by which it is to be used.

Lead lines should be measured frequently while wet and the correctness of the marking verified. The distance from the leadsman's hand to the water's edge should be ascertained in order that proper allowance may be made therefor in taking soundings at night.

19. The deep-sea lead may be *armed* by filling with tallow a hole hollowed out in its lower end, by which means a sample of the bottom is brought up.

THE SOUNDING MACHINE.

20. This machine possesses advantages over the deep-sea lead, for which it is a substitute, in that soundings may be obtained at great depths and with rapidity and accuracy without stopping the ship. It consists essentially of a stand holding a reel upon which is wound the sounding wire, and which is controlled by a suitable brake. Crank handles are provided for reeling in the wire after the sounding has been taken. Attached to the outer end of the wire is the lead, which has a cavity at its lower end for the reception of the tallow for arming. Above the lead is a cylindrical case containing the depth-registering mechanism; various devices are in use for this purpose, all depending, however, upon the increasing pressure of the water with increasing depths.

21. In the *Lord Kelvin machine* a slender glass tube is used, sealed at one end and open at the other, and coated inside with a chemical substance which changes color upon contact with sea water; this tube is placed, closed end up, in the metal cylinder; as it sinks the water rises in the tube, the contained air being compressed with a force dependent upon the depth. The limit of discoloration is marked by a clearly defined line, and the depth of the sounding corresponding to this line is read off from a scale. Tubes that have been used in comparatively shallow water may be used again where the water is known to be deeper.

22. A tube whose inner surface is *ground* has been substituted for the chemical-coated tube, ground glass, when wet, showing clear. The advantage of these tubes is that they may be used an indefinite number of times if thoroughly dried. To facilitate drying, a rubber cap is fitted to the upper end, which, when removed, admits of a circulation of the air through the tube.

23. As a substitute for the glass tubes a mechanical *depth recorder* contained in a suitable case has been used. In this device the pressure of the water acts upon a piston against the tension of a spring. A scale with an index pointer records the depth reached. The index pointer must be set at zero before each sounding.

24. Since the action of the sounding machine, when glass tubes are used, depends upon the compression of the air, the barometric pressure of the atmosphere must be taken into account when accurate results are required. The correction consists in *increasing* the indicated depth by a fractional amount according to the following table:

Bar. reading.	Increase.
"	
29.75	One-fortieth.
30.00	One-thirtieth.
30.50	One-twentieth.
30.75	One-fifteenth.

THE MARINER'S COMPASS.[a]

25. The *Mariner's Compass* is an instrument consisting either of a single magnet, or, more usually, of a group of magnets, which, being attached to a graduated circle pivoted at the center and allowed to swing freely in a horizontal plane, has a tendency, when not affected by disturbing magnetic features within the ship, to lie with its magnetic axis in the plane of the earth's magnetic meridian, thus affording a means of determining the azimuth, or horizontal angular distance from that meridian, of the ship's course and of all visible objects, terrestrial or celestial.

26. The circular card of the compass is divided on its periphery into 360°, frequently numbered from 0° at North and South to 90° at East and West; also into thirty-two divisions of 11¼° each, called *points*, the latter being further divided into *half-points* and *quarter-points;* still finer subdivisions, *eighth-points*, are sometimes used, though not indicated on the card. A system of numbering the degrees from 0° to 360°, always increasing toward the right, is shown in figure 2. This system is in use in the United States Navy and by the mariners of some foreign nations, and its general adoption would carry with it certain undoubted advantages.

27. *Boxing the Compass* is the process of naming the points in their order, and is one of the first things to be learned by the young mariner. The four principal points are called *cardinal points* and are named North, South, East, and West; each differs in direction from the adjacent one by 90°, or 8 points. Midway between the cardinal points, at an angular distance of 45°, or 4 points, are the *inter-cardinal* points, named according to their position Northeast, Southeast, etc. Midway between each cardinal and inter-cardinal point, at an angular distance of 22½°, or 2 points, is a point whose name is made up of a combination of that of the cardinal with that of the inter-cardinal point: North-Northeast, East-Northeast, East-Southeast, etc. At an angular distance of 1 point, or 11¼°, from each cardinal and inter-cardinal point (and therefore midway between it and the 22½°-division last described), is a point which bears the name of that cardinal or inter-cardinal point joined by the word *by* to that of the cardinal point in the direction of which it lies: North by East, Northeast by North, Northeast by East, etc.

[a] The U. S. Navy Standard No. 1 Compass Card is a plane annular ring, outside diameter 7½ inches, inside diameter 4½ inches; graduated to single degrees, with each 5-degree mark accentuated, and each 10-degree graduation numbered in bold figures, from 0° to 350°. In addition to the degree graduations, there are shown only the eight cardinal and inter-cardinal points.

The No. 2 Compass Card has a diameter of 6¾ inches and is identical with the No. 1 Card in all other respects.

Other types of Navy Compasses have cards which differ from that of the No. 1 only in their diameter and size of minimum graduations. The No. 3 Card is 5 inches in diameter and is graduated to 2 degrees. The Boat Compass Card is 4 inches in diameter, with 5-degree graduations.

In boxing by fractional points, it is evident that each division may be referred to either of the whole points to which it is adjacent; for instance, NE. by N. ½ N. and NNE. ½ E. would describe the same division. It is the custom in the United States Navy to box *from* North and South *toward* East and West, excepting that divisions adjacent to a cardinal or inter-cardinal point are always referred to that point; as

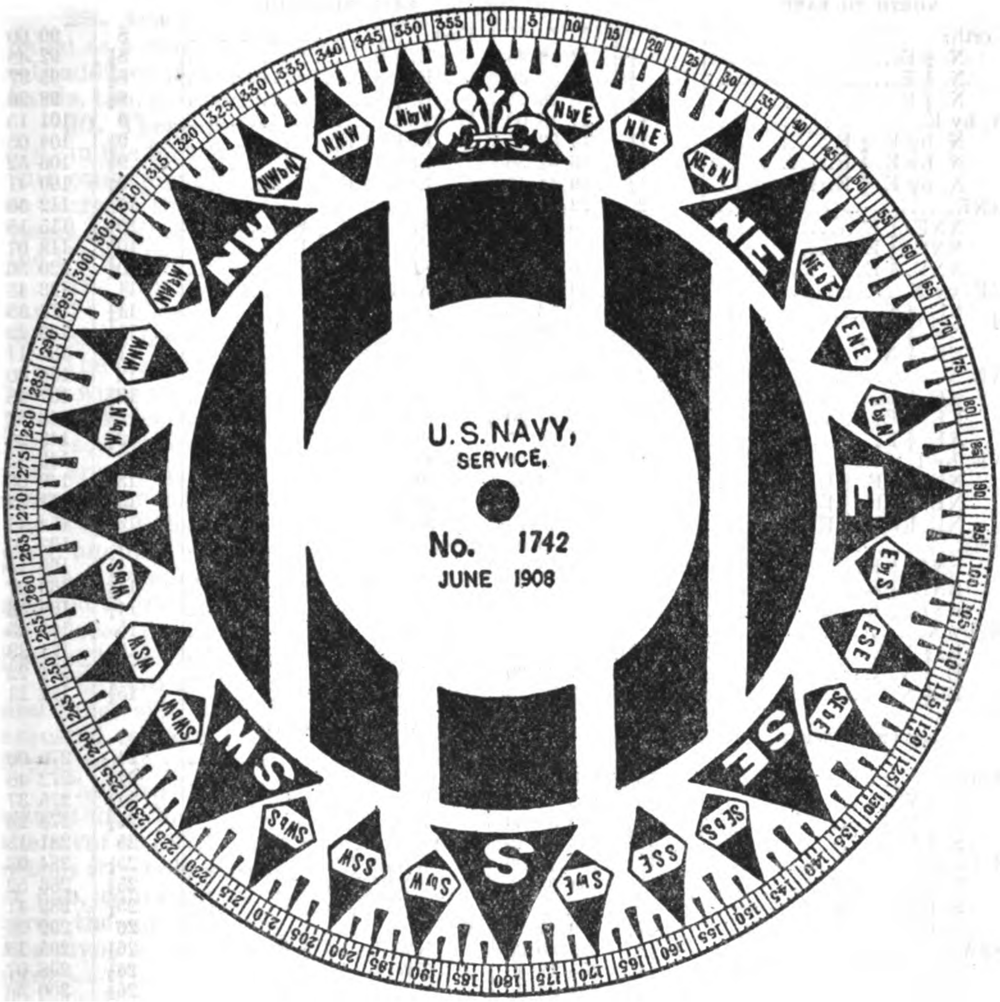

FIG. 2.

N. ½ E., N. by E. ½ E., NNE. ½ E., NE. ½ N., etc. Some mariners, however, make it a practice to box *from* each cardinal and inter-cardinal point *toward* a 22½°-point (NNE., ENE., etc.); as N. ½ E., N. by E. ½ E., NE. by N. ½ N., NE. ½ N., etc.

The names of the whole points, together with fractional points (according to the nomenclature of the United States Navy), are given in the following table, which shows also the degrees, minutes, and seconds from North or South to which each division corresponds:

	Points.	Angular measure.		Points.	Angular measure.
NORTH TO EAST.			EAST TO SOUTH.		
		° ′ ″			
North:			East	8	90 00 00
N. ¼ E.	¼	2 48 45	E. ¼ S.	8¼	92 48 45
N. ½ E.	½	5 37 30	E. ½ S.	8½	95 37 30
N. ¾ E.	¾	8 26 15	E. ¾ S.	8¾	98 26 15
N. by E.	1	11 15 00	E. by S.	9	101 15 00
N. by E. ¼ E.	1¼	14 03 45	ESE. ¾ E.	9¼	104 03 45
N. by E. ½ E.	1½	16 52 30	ESE. ½ E.	9½	106 52 30
N. by E. ¾ E.	1¾	19 41 15	ESE. ¼ E.	9¾	109 41 15
NNE.	2	22 30 00	ESE.	10	112 30 00
NNE. ¼ E.	2¼	25 18 45	SE. by E. ¾ E.	10¼	115 18 45
NNE. ½ E.	2½	28 07 30	SE. by E. ½ E.	10½	118 07 30
NNE. ¾ E.	2¾	30 56 15	SE. by E. ¼ E.	10¾	120 56 15
NE. by N.	3	33 45 00	SE. by E.	11	123 45 00
NE. ¾ N.	3¼	36 33 45	SE. ¾ E.	11¼	126 33 45
NE. ½ N.	3½	39 22 30	SE. ½ E.	11½	129 22 30
NE. ¼ N.	3¾	42 11 15	SE. ¼ E.	11¾	132 11 15
NE.	4	45 00 00	SE.	12	135 00 00
NE. ¼ E.	4¼	47 48 45	SE. ¼ S.	12¼	137 48 45
NE. ½ E.	4½	50 37 30	SE. ½ S.	12½	140 37 30
NE. ¾ E.	4¾	53 26 15	SE. ¾ S.	12¾	143 26 15
NE. by E.	5	56 15 00	SE. by S.	13	146 15 00
NE. by E. ¼ E.	5¼	59 03 45	SSE. ¾ E.	13¼	149 03 45
NE. by E. ½ E.	5½	61 52 30	SSE. ½ E.	13½	151 52 30
NE. by E. ¾ E.	5¾	64 41 15	SSE. ¼ E.	13¾	154 41 15
ENE.	6	67 30 00	SSE.	14	157 30 00
ENE. ¼ E.	6¼	70 18 45	S. by E. ¾ E.	14¼	160 18 45
ENE. ½ E.	6½	73 07 30	S. by E. ½ E.	14½	163 07 30
ENE. ¾ E.	6¾	75 56 15	S. by E. ¼ E.	14¾	165 56 15
E. by N.	7	78 45 00	S. by E.	15	168 45 00
E. ¾ N.	7¼	81 33 45	S. ¾ E.	15¼	171 33 45
E. ½ N.	7½	84 22 30	S. ½ E.	15½	174 22 30
E. ¼ N.	7¾	87 11 15	S. ¼ E.	15¾	177 11 15
SOUTH TO WEST.			WEST TO NORTH.		
South	16	180 00 00	West	24	270 00 00
S. ¼ W.	16¼	182 48 45	W. ¼ N.	24¼	272 48 45
S. ½ W.	16½	185 37 30	W. ½ N.	24½	275 37 30
S. ¾ W.	16¾	188 26 15	W. ¾ N.	24¾	278 26 15
S. by W.	17	191 15 00	W. by N.	25	281 15 00
S. by W. ¼ W.	17¼	194 03 45	WNW. ¾ W.	25¼	284 03 45
S. by W. ½ W.	17½	196 52 30	WNW. ½ W.	25½	286 52 30
S. by W. ¾ W.	17¾	199 41 15	WNW. ¼ W.	25¾	289 41 15
SSW.	18	202 30 00	WNW.	26	292 30 00
SSW. ¼ W.	18¼	205 18 45	NW. by W. ¾ W.	26¼	295 18 45
SSW. ½ W.	18½	208 07 30	NW. by W. ½ W.	26½	298 07 30
SSW. ¾ W.	18¾	210 56 15	NW. by W. ¼ W.	26¾	300 56 15
SW. by S.	19	213 45 00	NW. by W.	27	303 45 00
SW. ¾ S.	19¼	216 33 45	NW. ¾ W.	27¼	306 33 45
SW. ½ S.	19½	219 22 30	NW. ½ W.	27½	309 22 30
SW. ¼ S.	19¾	222 11 15	NW. ¼ W.	27¾	312 11 15
SW.	20	225 00 00	NW.	28	315 00 00
SW. ¼ W.	20¼	227 48 45	NW. ¼ N.	28¼	317 48 45
SW. ½ W.	20½	230 37 30	NW. ½ N.	28½	320 37 30
SW. ¾ W.	20¾	233 26 15	NW. ¾ N.	28¾	323 26 15
SW. by W.	21	236 15 00	NW. by N.	29	326 15 00
SW. by W. ¼ W.	21¼	239 03 45	NNW. ¾ W.	29¼	329 03 45
SW. by W. ½ W.	21½	241 52 30	NNW. ½ W.	29½	331 52 30
SW. by W. ¾ W.	21¾	244 41 15	NNW. ¼ W.	29¾	334 41 15
WSW.	22	247 30 00	NNW.	30	337 30 00
WSW. ¼ W.	22¼	250 18 45	N. by W. ¾ W.	30¼	340 18 45
WSW. ½ W.	22½	253 07 30	N. by W. ½ W.	30½	343 07 30
WSW. ¾ W.	22¾	255 56 15	N. by W. ¼ W.	30¾	345 56 15
W. by S.	23	258 45 00	N. by W.	31	348 45 00
W. ¾ S.	23¼	261 33 45	N. ¾ W.	31¼	351 33 45
W. ½ S.	23½	264 22 30	N. ½ W.	31½	354 22 30
W. ¼ S.	23¾	267 11 15	N. ¼ W.	31¾	357 11 15
			North	32	360 00 00

28. The compass card is mounted in a bowl which is carried in *gimbals*, thus enabling the card to retain a horizontal position while the ship is pitching and rolling. A vertical black line called the *lubber's line* is marked on the inner surface of the bowl, and the compass is so mounted that a line joining its pivot with the lubber's line is parallel to the keel line of the vessel; thus the lubber's line always indicates the compass direction of the ship's head.

29. According to the purpose which it is designed to fulfill, a compass is designated as a *Standard, Steering, Check,* or *Boat Compass.* On United States naval vessels additional compasses are designated as follows: Maneuvering, battle, auxiliary battle, top, and conning-tower compasses.

30. There are two types of magnetic compass in use, the *liquid* or *wet* and the *dry;* in the former the bowl is filled with liquid, the card being thus partially buoyed with consequent increased ease of working on the pivot, and the liquid further serving to decrease the vibrations of the card when deflected by reason of the motion of the vessel or other cause. On account of its advantages the liquid compass is used in the United States Navy.

31. THE NAVY SERVICE 7½-INCH LIQUID COMPASS.—This consists of a skeleton card 7½ inches in diameter, made of tinned brass, resting on a pivot in liquid, with provisions for two pairs of magnets symmetrically placed.

The magnet system of the card consists of four cylindrical bundles of steel wires; these wires are laid side by side and magnetized as a bundle between the poles of a powerful electro-magnet. They are afterwards placed in a cylindrical case, sealed, and secured to the card. Steel wires made up into a bundle were adopted because they are more homogeneous, can be more perfectly tempered, and for the same weight give greater magnetic power than a solid steel bar.

Two of the magnets are placed parallel to the north and south diameter of the card, and on the chords of 15° (nearly) of a circle passing through their extremities. These magnets penetrate the air vessel, to which they are soldered, and are further secured to the bottom of the ring of the card. The other two magnets of the system are placed parallel to the longer magnets on the chords of 45° (nearly) of a circle passing through their extremities and are secured to the bottom of the ring of the card.

The card is of a curved annular type, the outer ring being convex on the upper and inner side, and is graduated to read to one-quarter point, a card circle being adjusted to its outer edge and divided to half degrees, with legible figures at each 5°, for use in reading bearings by an azimuth circle or in laying the course to degrees.

The card is provided with a concentric spheroidal air vessel, to buoy its own weight and that of the magnets, allowing a pressure of between 60 and 90 grains on the pivot at 60° F.; the weight of the card in air is 3,060 grains. The air vessel has within it a hollow cone, open at its lower end, and provided with the pivot bearing or cap, containing a sapphire, which rests upon the pivot and thus supports the card; the cap is provided with adjusting screws for accurately centering the card. The pivot is fastened to the center of the bottom of the bowl by a flanged plate and screws. Through this plate and the bottom of the bowl are two small holes which communicate with the expansion chamber and admit of a circulation of the liquid between it and the bowl. The pivot is of gun metal with an iridium cap.

The card is mounted in a bowl of cast bronze, the glass cover of which is closely packed with rubber, preventing the evaporation or leakage of the liquid, which entirely fills the bowl. This liquid is composed of 45 per cent pure alcohol and 55 per cent distilled water, and remains liquid below −10° F.

The lubber's line is a fine line drawn on an enameled plate on the inside of the bowl, the inner surface of the latter being covered with an insoluble white paint.

Beneath the bowl is a metallic self-adjusting expansion chamber of elastic metal, by means of which the bowl is kept constantly full without the show of bubbles or the development of undue pressure caused by the change in volume of the liquid due to changes of temperature.

The rim of the compass bowl is made rigid and its outer edge turned strictly to gauge to receive the azimuth circle.

32. THE DRY COMPASS.—The *Lord Kelvin Compass*, which may be regarded as the standard for the dry type, consists of a strong paper card with the central parts cut away and its outer edge stiffened by a thin aluminum ring. The pivot is fitted with an iridium point, upon which rests a small light aluminum boss fitted with a sapphire bearing. Radiating from this boss are 32 silk threads whose outer ends are made fast to the inner edge of the compass card; these threads sustain the weight of the suspended card, and as they possess some elasticity, tend to decrease the shocks due to motion.

Eight small steel wire needles, 3¼ to 2 inches long, are secured normally to two parallel silk threads, and are slung from the aluminum rim of the card by other silk threads which pass through eyes in the ends of the outer pair of needles. The needles are below the radial threads, thus keeping the center of gravity low.

33. The Gyro Compass.—This compass, which has recently been developed, consists essentially of a rapidly spinning rotor, usually driven by a three-phase alternating current of electricity, at a rate varying according to the type, from 8,000 to 21,000 revolutions per minute, and so suspended that it automatically places its axis approximately in the direction of the geographical meridian and permits of the reading of the heading of the ship, unaffected by any magnetic influence, from a graduated compass card like that in use on magnetic compasses. From the "master compass," which may be located in a compartment below, electrical connections are made to "repeating compasses" on the bridge, in the conning tower, or in the steering-engine room, so that the ship's true heading may be transmitted to any desired part of the vessel.

The action of the gyro compass, affected as it is by the earth's rotation under it, conforms to Foucault's general law that "a spinning body tends to swing around so as to place its axis parallel to the axis of any impressed forces, and so that its direction of rotation is the same as that of the impressed forces." Small corrections, depending upon the latitude, course, and speed, can be readily computed for application to the gyro compass readings either mechanically or by reference to tables.

34. The Azimuth Circle.—This is a necessary fitting for all compasses employed for taking bearings—that is, noting the directions—of either celestial or terrestrial objects. The instrument varies widely in its different forms; the essential features which all share consist in (*a*) a pair of sight vanes, or equivalent device, at the extremities of the diameter of a circle that revolves concentrically with the compass bowl, the line of sight thus always passing through the vertical axis of the compass; and (*b*) a system, usually of mirrors and prisms, by which the point of the compass card cut by the vertical plane through the line of sight—in other words, the compass direction—is brought into the field of view of the person making the observation. In some circles, for observing azimuths of the sun advantage is taken of the brightness of that body to reflect a pencil of light upon the card in such a manner as to indicate the bearing; such an azimuth circle is used in the United States Navy.

The azimuth circles should be tested occasionally for accuracy. This can best be done by mounting a standard compass on a tripod in a nonmagnetic spot on shore, in a locality where the variation has been accurately determined. The observed compass bearing of the sun should, of course, be the same as the computed magnetic bearing at any instant, the difference between the two, if any, being equal to the error of the compass or, what is more likely, the error of the azimuth circle. Any doubt in the matter may be removed by the use of two or more compasses. It will be frequently found that the error of the azimuth circle varies with the sun's altitude; this is due to the fact that the axis of the mirror is not normal to the plane passing through the sun, the 5-sided prism, and the center of the mirror.

35. Binnacles.—Compasses are mounted for use in stands known as *Binnacles,* of which there are two principal types—the *Compensating* and the *Noncompensating Binnacle,* so designated according as they are or are not equipped with appliances by which the deviation of the compass, or error in its indications due to disturbing magnetic features within the ship may be compensated.

Binnacles may be of wood or of some nonmagnetic metal; all contain a compass chamber within which the compass is suspended in its gimbal ring, the knife edges upon which it is suspended resting in V-shaped bearings; an appropriate method is supplied for centering the compass. A hood is provided for the protection of the compass and for lighting it at night. Binnacles must be rigidly secured to the deck of the vessel in such position that the lubber's line of the compass gives true indications of the direction of the ship's head.

The position of the various binnacles on shipboard and the height at which they carry the compass must be chosen with regard to the purpose which the compass is to serve, having in mind the magnetic conditions of the ship.

Compensating binnacles contain the appliances for carrying the various correctors used in the compensation of the deviation of the compass. These consist of (*a*) a system of permanent magnets for semicircular deviation, placed in a magnetic chamber lying immediately beneath the compass chamber, so arranged as to permit variation in the height and number of the magnets employed; (*b*) a pair of arms projecting horizontally from the compass chamber and supporting masses of soft iron for quadrantal deviation; (*c*) a central tube in the vertical axis of the binnacle for a permanent magnet used to correct the heeling error; and (*d*) an attachment, sometimes fitted, for securing a vertical soft-iron rod, or "Flinders bar," used in certain cases for correction of a part of the semicircular deviation. An explanation of the various terms here used, together with the method of compensating the compass, will be given in Chapter III.

THE PELORUS.

36. This instrument consists of a circular flat metallic ring, mounted in gimbals, upon a vertical standard at some point on board ship affording a clear view for taking bearings. The inner edge of this ring is engraved in degrees—the 360° and the 180° marks indicating a fore-and-aft line parallel to the keel of the ship. Within this ring a ground-glass dial is pivoted concentrically. This ground-glass dial has painted upon it a compass rose divided into points and subdivisions and into 360°. This dial is capable of revolution, but may be clamped to the outside ring. Pivoted concentrically with the flat ring and the glass dial is a horizontal bar carrying at both of its extremes a sight vane, or, mounted upon the bar and parallel to it, a telescope containing cross wires. This sight-vane bar can be clamped in any position independently of the ground-glass dial, which can be moved freely beneath it. An indicator showing the direction the sight-vane bar points can be read upon the compass card on the glass dial.

The instrument is used for taking bearings of distant objects, and, at times, may be more convenient than the standard compass for that purpose on account of the better view commanded by its position, as well as because it may be made to eliminate compass errors from observed bearings, thus reducing the bearings observed to magnetic or true bearings. If the glass dial be revolved until the degree of demarcation which is coincident with the right-ahead marking on the flat ring is the same as that which points to the lubber's line of the standard compass, then all directions indicated by the glass will be parallel to the corresponding directions of the standard compass, and all bearings taken by the pelorus will be identical with those taken by the compass (leaving out of the question the difference due to the distance which separates them). If it is known that the ship's compass has a certain error due to deviation of the compass and if the glass dial be set to allow for this deviation, then all bearings read from the pelorus will be magnetic. If the dial be set allowing for both deviation and variation of the compass, then all bearings read will be true. It should be noted, however, that the bearings taken by pelorus will be accurate only when the ship is on her exact course by standard compass. For this reason it is usual to take a bearing by pelorus, at the same time noting the heading by standard compass, and clamping the sight vane; then, moving the glass dial until the direction opposite the dead-ahead mark is the same as that noted by the standard compass, the bearing observed (corrected for the variation and for the deviation of the heading at the instant of observation) will be the true bearing.

The pelorus described above is of the most modern type and is fitted for illuminating the glass dial from below in order to facilitate night work.

Peloruses whose dials are controlled by a master gyroscopic compass of course indicate at once the true bearing of the object observed.

When fitted with a telescope the pelorus may be used to take the azimuth of stars.

The standard compass is usually located in the ship in the central fore-and-aft line which is established from the builders' marks placed in that vicinity. The standard compass being located, all peloruses may be oriented from it by any one of the following methods:

(*a*) By making the azimuth of a celestial body, taken by the pelorus, coincide with the simultaneous azimuth of the same body taken by the standard compass.

(*b*) By a similar process with distant objects; and the parallax may be entirely eliminated in an apparently near object, in view of the moderate distance that usually separates the two instruments on board ship.

(*c*) By reciprocal bearings between the correct instrument and the instrument to be established; it is evident that if the lubber lines of the two instruments are both in the direction of the keel line, the bearing of the sight vane of each from the other (one being reversed) should coincide.

(*d*) By computing the angle subtended at the pelorus by the fore-and-aft line through the pelorus and the line drawn through the pelorus to the jack staff, and setting the pelorus at this angle and sighting on the jack staff.

THE CHART.

37. A nautical *chart* is a miniature representation upon a plane surface, in accordance with a definite system of projection or development, of a portion of the navigable waters of the world. It generally includes the outline of the adjacent land, together with the surface forms and artificial features that are useful as aids to navigation, and sets forth the depths of water, especially in the near approaches to the land, by soundings that are fixed in position by accurate determinations. Except in charts of harbors or other localities so limited that the curvature of the earth is inappreciable on the scale of construction, a nautical chart is always framed over with a network of parallels of latitude and meridians of longitude in relation to which the features to be depicted on the chart are located and drawn; and the mathematical relation between the meridians and parallels of the chart and those of the terrestrial sphere determines the method of measurement that is to be employed on the chart and the special uses to which it is adapted.

38. There are three principal systems of projection in use: (*a*) the *Mercator*, (*b*) the *polyconic*, and (*c*) the *gnomonic;* of these the Mercator is by far the most generally used for purposes of navigation proper, while the polyconic and the gnomonic charts are employed for nautical purposes in a more restricted manner, as for plotting surveys or for facilitating great circle sailing.

39. The Mercator Projection.—The *Mercator Projection*, so called, may be said to result from the development, upon a plane surface, of a cylinder which is tangent to the earth at the equator, the various points of the earth's surface having been projected upon the cylinder in such manner that the *loxodromic curve* or *rhumb line* (art. 6, Chap. I) appears as a right line preserving the same angle of bearing with respect to the intersected meridians as does the ship's track.

In order to realize this condition, the line of tangency, which coincides with the earth's equator, being the circumference of a right section of the cylinder, will appear as a right line on the development; while the series of elements of the cylinder corresponding to the projected terrestrial meridians will appear as equidistant right lines, parallel to each other and perpendicular to the equator of the chart, maintaining the same relative positions and the same distance apart on that equator as the meridians have on the terrestrial spheroid. The series of terrestrial parallels will also appear as a system of right lines parallel to each other and to the equator, and will so intersect the meridians as to form a system of rectangles whose altitudes, for successive intervals of latitude, must be variable, increasing from the equator in such manner that the angles made by the rhumb line with the meridian on the chart may maintain the required equality with the corresponding angles on the spheroid.

40. Meridional Parts.—At the equator a degree of longitude is equal to a degree of latitude, but in receding from the equator and approaching the pole, while the degrees of latitude remain always of the same length (save for a slight change due to the fact that the earth is not a perfect sphere), the degrees of longitude become less and less.

Since, in the Mercator projection, the degrees of longitude are made to appear everywhere of the same length, it becomes necessary, in order to preserve the proportion that exists at different parts of the earth's surface between degrees of latitude and degrees of longitude, that the former be increased from their natural lengths, and such increase must become greater and greater the higher the latitude.

The length of the meridian, as thus increased, between the equator and any given latitude, expressed in minutes at the equator as a unit, constitutes the number of *Meridional Parts* corresponding to that latitude. The Table of Meridional Parts or Increased Latitudes (Table 3), computed for every minute of latitude between 0° and 80°, affords facilities for constructing charts on the Mercator projection and for solving problems in Mercator sailing.

41. To Construct a Mercator Chart.[a]—If the chart for which a projection is to be made includes the equator, the values to be measured off are given directly by Table 3. If the equator does not come upon the chart, then the parallels of latitude to be laid down should be referred to a *principal parallel*, preferably the lowest parallel to be drawn on the chart. The distance of any other parallel of latitude from the principal parallel is then the difference of the values for the two taken from Table 3.

The values so found may either be measured off, without previous numerical conversion, by means of a diagonal scale constructed on the chart, or they may be laid down on the chart by means of any properly divided scale of yards, meters, feet, or miles, after having been reduced to the scale of proportions adopted for the chart.

If, for example, it be required to construct a chart on a scale of one-quarter of an inch to five minutes of arc on the equator, a diagonal scale may first be constructed, on which ten meridional parts, or ten minutes of arc on the equator, have a length of half an inch.

It may often be desirable to adapt the scale to a certain allotment of paper. In this case, the lowest and the highest parallels of latitude may first be drawn on the sheet on which the transfer is to be made. The distance between these parallels may then be measured, and the number of meridional parts between them ascertained. Dividing the distance by this number will then give the length of one meridional part, or the quantity by which *all* the meridional parts taken from Table 3 must be multiplied. This quantity will represent the *scale of the chart*. If it occurs that the limits of longitude are a governing consideration, the case may be similarly treated.

Example: Let a projection be required for a chart of 14° extent in longitude between the parallels of latitude 20° 30′ and 30° 25′, and let the space allowable on the paper between these parallels measure 10 inches.

Entering the column in Table 3 headed 20°, and running down to the line marked 30′ in the side column, will be found 1248.9; then, entering the column 30°, and running down to the line 25′, will be found 1905.5. The difference, or $1905.5-1248.9=653.6$, is the value of the meridional arc between these latitudes, for which 1′ of arc of the equator is taken as the unit. On the intended projection, therefore, 1′ of arc of longitude will measure $\frac{10^{\text{in.}}}{656.6}=0.0152$ inch, which will be the scale of the chart. For the sake of brevity call it 0.015. By this quantity all the values derived from Table 3 will have to be multiplied before laying them down on the projection, if they are to be measured on a diagonal scale of one inch.

Draw in the center of the sheet a straight line, and assume it to be the middle meridian of the chart. Construct very carefully on this line a perpendicular near the lower border of the sheet, and assume this perpendicular to be the parallel of latitude 20° 30′; this will be the southern inner neat line of the chart. From the intersection of the lines lay off on the parallel, on each side of the middle meridian, seven degrees of longitude, or distances each equal to $0.015\times60\times7=6.3$ inches; and through the points thus obtained draw lines parallel to the middle meridian, and these will be the eastern and western neat lines of the chart.

In order to construct the parallel of latitude for 21° 00′, find, in Table 3, the meridional parts for 21° 00′, which are 1280.8. Subtracting from this number the number for 20° 30′, and multiplying the difference by 0.015, we obtain 0.478 inch, which is the distance on the chart between 20° 30′ and 21° 00′. On the meridians

[a] This construction for the purpose of plotting lines of position in ordinary navigation will often be unnecessary if use is made of the Position Plotting Sheets published by the Hydrographic Office.

lay off distances equal to 0.478 inch, and through the three points thus obtained draw a straight line, which will be the parallel of 21° 00′.

Proceed in the same manner to lay down all the parallels answering to full degrees of latitude; the distances will be respectively:

$$0^{in}.015 \times (1344.9 - 1248.9) = 1.440 \text{ inches.}$$
$$0^{in}.015 \times (1409.5 - 1248.9) = 2.409 \text{ inches.}$$
$$0^{in}.015 \times (1474.5 - 1248.9) = 3.384 \text{ inches, etc.}$$

Thus will be shown the parallels of latitude 22° 00′, 23° 00′, 24° 00′, etc. Finally, lay down in the same way the parallel of latitude 30° 25′, which will be the northern inner neat line of the chart.

A degree of longitude will measure on this chart $0^{in}.015 \times 60 = 0^{in}.9$. Lay off, therefore, on the lowest parallel of latitude drawn on the chart, on a middle one, and on the highest parallel, measuring from the middle meridian toward each side, the distances of $0^{in}.9$, $1^{in}.8$, $2^{in}.7$, $3^{in}.6$, etc., in order to determine the points where meridians answering to full degrees cross the parallels drawn on the chart. Through the points thus found draw the meridians. Draw then the outer neat lines of the chart at a convenient distance outside of the inner neat lines, and extend to them the meridians and parallels. Between the inner and outer neat lines of the chart subdivide the degrees of latitude and longitude as minutely as the scale of the chart will permit, the subdivisions of the degrees of longitude being found by dividing the degrees into equal parts, and the subdivisions of the degrees of latitude being accurately found in the same manner as the full degrees of latitude previously described, though it will generally be found sufficiently exact to make even subdivisions of the degrees, as in the case of the longitude.

The subdivisions between the two eastern as well as those between the two western neat lines will serve for measuring or estimating terrestrial distances. Distances between points bearing North and South of each other may be ascertained by referring them to the subdivisions between the same parallels. Distances represented by lines at an angle to the meridians (loxodromic lines) may be measured by taking between the dividers a small number of the subdivisions near the middle latitude of the line to be measured, and stepping them off on that line. If, for instance, the terrestrial length of a line running at an angle to the meridians between the parallels of latitude of 24° 00′ and 29° 00′ be required, the distance shown on the neat space between 26° 15′ and 26° 45′ (=30 nautical miles) may be taken between the dividers and stepped off on that line.

42. Coast lines and other positions are plotted on the chart by their latitude and longitude. A chart may be transferred from any other projection to that of Mercator by drawing a system of corresponding parallels of latitude and meridians over both charts so close to each other as to form minute squares, and then the lines and characters contained in each square of the map to be transferred may be copied by the eye in the corresponding squares of the Mercator projection.

Since the unit of measure, the mile or minute of latitude, has a different value in every latitude, there is an appearance of distortion in a Mercator chart that covers any large extent of surface; for instance, an island near the pole will be represented as being much larger than one of the same size near the equator, due to the different scale used to preserve the character of the projection.

43. THE POLYCONIC PROJECTION.—This projection is based upon the development of the earth's surface on a series of cones, a different one for each parallel of latitude, each one having the parallel as its base, and its vertex in the point where a tangent to the earth at that latitude intersects the earth's axis. The degrees of latitude and longitude on this chart are projected in their true length, and the general distortion of the figure is less than in any other method of projection, the relative magnitudes being closely preserved.

A straight line on the polyconic chart represents a near approach to a great circle, making a slightly different angle with each successive meridian as the meridians converge toward the pole and are theoretically curved lines; but it is only on charts of large extent that this curvature is apparent; the parallels are also curved, this fact being apparent to the eye upon all excepting the largest scale charts.

This method of projection is especially adapted to the plotting of surveys; it is also employed to some extent in the charts of the United States Coast and Geodetic Survey.

44. GNOMONIC PROJECTION.—This is based upon a system in which the plane of projection is tangent to the earth at some given point; the eye of the spectator is situated at the center of the sphere, where, being at once in the plane of every great circle, it will see all such circles projected as straight lines where the visual rays passing through them intersect the plane of projection. In a gnomonic chart, the straight line between any two points represents the arc of a great circle, and is therefore the shortest line between those points.

Excepting in the polar regions, for which latitudes the Mercator projection can not be constructed, the gnomonic charts are not used for general navigating purposes. Their greatest application is to afford a ready means of finding the course and distance at any time in great circle sailing, the method of doing which will be explained in Chapter V.

45. MERIDIANS ADOPTED IN THE CONSTRUCTION OF CHARTS.—The nautical charts published by the United States are based upon the meridian of Greenwich, and this meridian is also the origin of longitudes in use on the nautical charts published by the Governments of Argentina, Austria, Belgium, Brazil, Chile, Denmark, France, Germany, Great Britain, Holland (for all charts published at Batavia and for some published at The Hague), Italy, Japan, Norway, Russia, and Sweden.

In addition to the meridian of Greenwich, the meridian of Pulkowa Observatory, at St. Petersburg, in longitude 30° 19′ 40″ east of Greenwich, is sometimes referred to in the Russian charts. At one time the Royal Observatory at Naples, in longitude 14° 15′ 26″ east of Greenwich, was referred to in the Italian charts, and the observatory at Christiania, in longitude 10° 43′ 23″ east of Greenwich, was referred to in the Norwegian charts.

The French charts are based both upon the meridian of Greenwich and of the Observatory at Paris, which has been determined to be in longitude 2° 20′ 14.6″ east of Greenwich. The longitudes of a few Dutch charts published at The Hague are reckoned from the meridian of the west tower of the cathedral at Amsterdam, which is in longitude 4° 53′ 01.5″ east of Greenwich. Portuguese charts refer to the meridian of the observatory of Lisbon Castle, which is 9° 07′ 54.86″ west of Greenwich, and to the meridian of Greenwich. In Spain the meridian of San Fernando Observatory, at Cadiz, which is in longitude 6° 12′ 20″ west of Greenwich, and also the meridian of Greenwich, are used.

46. QUALITY OF BOTTOM.—The following table shows the qualities of the bottom, as expressed on charts of various nations:

United States.	English.	French.	Italian.	Spanish.	German.
Clay............C.	Clay............cl.	Argile..........A.	Argila.........arg.	Arcillo or Barro.arc.	Lehm.............L.
Coral...........Co.	Coral...........crl.	Corall.........Cor.	Corállo.........crl.	Coral............cl.	Korallen........Kor.
Gravel..........G.	Gravel..........g.	Gravier........Gr.	Rena or Ghiaja.gh.	Cascájo..........Co.	Kies..............k.
Mud............M.	Mud............m.	Vase............V.	Fango...........f.	Fango or Luno...F.	Schlamm.......Schl.
Rocky.........rky.	Rock............rk.	Roche..........R.	Roccia...........r.	Piedra or Roca.P. or r.	Felsig...........Fls.
Sand............S.	Sand............s.	Sable............S.	Sábbia or Aréna..s.	Arena............A.	Sand.............Sd.
Shells..........Sh.	Shells..........sh.	Coquille......Coq.	Conchiglia.......c.	Conchuela.......ca.	Muscheln.........M.
Stone...........St.	Stones..........st.	Pierre...........P.	Pietre...........p.	Piedra...........P.	Stein.............St.
Weed.........Wd.	Weed.........wd.	Herb...........H.	Alga............alg.	Alga.............A.	Gras............Grs.
Fine...........fne.	Fine.............f.	Fin............fin.	Fino..............	Fina.............f.	Fein...............f.
Coarse..........crs.	Coarse...........c.	Gros.............g.	Grosso............	Gruesa...........g.	Grob..............gb.
Stiff............stf.	Stiff............stf.	Dure............d.	Tenace............	Tenaz..............	Schlick...........sk.
Soft............sft.	Soft............sft.	Molle...........m.	Molle..............	Blando........bdo.	Weich.........Wch.
Black..........bk.	Black.........blk.	Noire...........n.	Nero..............	Negro.............n.	Schwarz.......schw.
Red............rd.	Red............rd.	Rouge...........r.	Rosso.............	Rojo..............r.	Roth..............r.
Yellow..........yl.	Yellow..........y.	Jaune............j.	Giallo.............	Amarillo.......am.	Gelb...............g.
Gray...........gy.					

47. Measures of Depth.—The following table shows the units of measure employed in expressing the soundings in the more modern nautical charts of foreign nations together with their equivalents in the units of measure used in the charts published by the United States:

Nationality of chart.	Unit of soundings.	Equivalent in United States units.		Nationality of chart.	Unit of soundings.	Equivalent in United States units.	
		Feet.	Fathoms.			Feet.	Fathoms.
Argentine...	Metro..........	3.281	0.547	Japanese.....	Fathom........	6.000	1.000
Austrian....	Metro..........	3.281	0.547	Norwegian...	Metre..........	3.281	0.547
	or faden........	6.223	1.037		or favn........	6.176	1.029
Belgian......	Metre..........	3.281	0.547	Portuguese...	Metro..........	3.281	0.547
Chilean......	Metro..........	3.281	0.547	Russian.....	Sajene........	6.000	1.000
Danish.....	favn...........	6.176	1.029	Spanish.....	Metro..........	3.281	0.547
Dutch.......	vadem..........	5.905	0.984		or braza........	5.492	0.914
	or metre.......	3.281	0.547	Swedish......	Metre..........	3.281	0.547
French......	Metre..........	3.281	0.547		or famn.......	5.844	0.974
German.....	Metre..........	3.281	0.547	British.......	Fathom........	6.000	1.000
Italian.....	Metro..........	3.281	0.547				

THE BAROMETER.


Fig. 3.

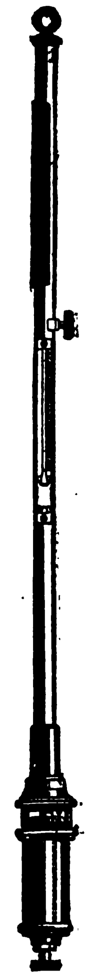
Fig. 4.

48. The *barometer* is an instrument for measuring the pressure of the atmosphere, and is of great service to the mariner in affording a knowledge of existing meteorological conditions and of the probable changes therein. There are two classes of barometer—*mercurial* and *aneroid*.

49. The Mercurial Barometer.—This instrument, invented by Torricelli in 1643, indicates the pressure of the atmosphere by the height of a column of mercury.

If a glass tube of uniform internal diameter somewhat more than 30 inches in length and closed at one end be completely filled with pure mercury, and then placed, open end down, in a cup of mercury (the open end having been temporarily sealed to retain the liquid during the process of inverting), it will be found that the mercury in the tube will fall until the top of the column is about 30 inches above the level of that which is in the cup, leaving in the upper part of the tube a vacuum. Since the weight of the column of mercury thus left standing in the tube is equal to the pressure by which it is held in position—namely, that of the atmospheric air—it follows that the height of the column is subject to variation upon variation of that pressure; hence the mercury falls as the pressure of the atmosphere decreases and rises as that pressure increases. The mean pressure of the atmosphere is equal to nearly 15 pounds to the square inch; the mean height of the barometer is about 30 inches.

50. In the practical construction of the barometer the glass tube which contains the mercury is encased in a brass tube, the latter terminating at the top in a ring to be used for suspension, and at the bottom in a flange, to which the several parts forming the cistern are attached. The upper part of the brass tube is partially cut away to expose the mercurial column for observation; abreast this opening is fitted a scale for measuring the height, and along the scale travels a *vernier* for exact reading; the motion of the vernier is controlled by a rack and pinion, the latter having a milled head accessible to the observer, by which the adjustment is made. In the middle of the brass tube is fixed a thermometer, the bulb of which is covered from the outside but open toward the mercury, and which, being nearly in contact with the glass tube, indicates the temperature of the mercury and not that of the external air; the central position of the column is selected in order that the mean temperature may be obtained—a matter of importance, as the temperature of the mercurial column must be taken into account in every accurate application of its reading.

51. In the arrangement of further details mercurial barometers are divided into two classes, according as they are to be used, as *Standards* (fig. 4) on shore, or as *Sea Barometers* (fig. 3) on shipboard.

In the Standard Barometer the scale and vernier are so graduated as to enable an observer to read the height of the mercurial column to the nearest 0.002 inch, while in the Sea Barometer the reading can not be made closer than 0.01 inch.

The instruments also differ in the method of obtaining the true height of the mercurial column at varying levels of the liquid in the cistern. It is evident that as the mercury in the tube rises, upon increase of atmospheric pressure, the mercury in the cistern must fall; and, conversely, when the mercurial column falls the amount of fluid in the cistern will thereby be increased and a rise of level will occur. As the height of the mercurial column is required above the existing level in the cistern, some means must be adopted to obtain the true height under varying conditions. In the Standard Barometer the mercury of the cistern is contained in a leather bag, against the bottom of which presses the point of a vertical screw, the milled head of the screw projecting from the bottom of the instrument and thus placing it under control of the observer. By this means the surface of the mercury in the cistern (which is visible through a glass casing) may be raised or lowered until it exactly coincides with that level which is chosen as the zero of the scale, and which is indicated by an ivory pointer in plain view.

In the Sea Barometer there is no provision for adjusting the level of the cistern to a fixed point, but compensation for the variable level is made in the scale graduations; a division representing an inch on the scale is a certain fraction short of the true inch, proper allowance being thus made for the rise in level which occurs with a fall of the column, and for the reverse condition.

Further modification is made in the Sea Barometer to adapt it to the special use for which intended. The tube toward its lower end is much contracted to prevent the oscillation of the mercurial column known as "pumping," which arises from the motion of the ship; and just below this point is a trap to arrest any small bubbles of air from finding their way upward. The instrument aboard ship is suspended in a revolving center ring, in gimbals, supported on a horizontal brass arm which is screwed to the bulkhead; a vertical position is thus maintained by the tube at all times.

52. The *vernier* is an attachment for facilitating the exact reading of the scale of the barometer, and is also applied to many other instruments of precision, as, for example, the sextant and theodolite. It consists of a metal scale similar in general construction to that of the instrument to which it is fitted, and arranged to move alongside of and in contact with the main scale.

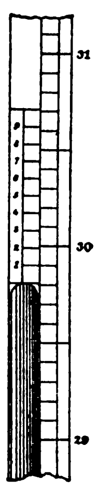

FIG. 5.

The general principle of the vernier requires that its scale shall have a total length exactly equal to some whole number of divisions of the scale of the instrument and that this length shall be subdivided into a number of parts equal to 1 more or 1 less than the number of divisions of the instrument scale which are covered; thus, if a space of 9 divisions of the main scale be designated as the length of the vernier, the vernier scale would be divided into either 8 or 10 parts.

Suppose that a barometer scale be divided into tenths of an inch and that a length of 9 divisions of such a scale be divided into 10 parts for a vernier (fig. 5); and suppose that the divisions of the vernier be numbered consecutively from zero at the origin to 10 at the upper extremity. If, now, by means of the movable rack and pinion, the bottom or zero division of the vernier be brought level with the top of the mercurial column, and that division falls into exact coincidence with a division of the main scale, then the height of the column will correspond with the scale reading indicated. In such a case the top of the vernier will also exactly coincide with a scale division, but none of the intermediate divisions will be evenly abreast of such a division; the division marked "1" will fall short of a scale division by one-tenth of 1 division of the scale, or by 0.01 inch; that marked "2" by two-tenths of a division, or 0.02 inch; and so on. If the vernier, instead of having the zero coincide with a scale division, has the division "1" in such coincidence, it follows that the mercurial column stands at 0.01 inch above that scale division which is next below the zero; for the division "2," at 0.02 inch; and similarly for the others. In the case portrayed in figure 5, the reading of the column is 29.81 inches, the scale division next below the zero being 29.80 inches, while the fact that the first division is abreast a mark of the scale shows that 0.01 inch must be added to this to obtain the exact reading.

Had an example been chosen in which 8 vernier divisions covered 9 scale divisions—that is, where the number of vernier divisions was 1 less than the number of scale divisions covered—the principle would still have applied. But, instead of the length of 1 division of the vernier falling short of a division of the scale by one-tenth the length of the latter, it would have fallen beyond by one-eighth. To read in such a case it would therefore be necessary to number the vernier divisions from up downward and to regard the subdivisions as $\frac{1}{80}$ instead of 0.01 inch.

It is a general rule that the smallest measure to which a vernier reads is equal to the length of 1 division of the scale divided by the number of divisions of the vernier; hence, by varying either the scale or the vernier, we may arrive at any subdivision that may be desired.

53. The Sea Barometer is arranged as described for the instrument assumed in the illustration; the scale divisions are tenths of an inch, and the vernier has 10 divisions, whence it reads to 0.01 inch. It is not necessary to seek a closer reading, as complete accuracy is not attainable in observing the height of a barometer on a vessel at sea, nor is it essential. The Standard Barometer on shore, however, is capable of very exact reading; hence each scale division is made equal to half a tenth, or 0.05 inch, while a vernier covering 24 such divisions is divided into 25 parts; hence the column may be read to 0.002 inch.

54. To adjust the vernier for reading the height of the mercurial column the eye should be brought exactly on a level with the top of the column; that is, the line of sight should be at right angles to the scale. When properly set, the front and rear edges of the vernier and the uppermost point of the mercury should all be in the line of sight. A piece of white paper, held at the back of the tube so as to reflect the light, assists in accurately setting the vernier by day, while a small bull's-eye lamp held behind the instrument enables the observer to get a correct reading at night. When observing the barometer it should hang freely, not being inclined by holding or even by touch, because any inclination will cause the column to rise in the tube.

55. Other things being equal, the mercury will stand higher in the tube when it is warm than when it is cold, owing to expansion. For the purposes of comparison, all barometric observations are reduced to a standard which assumes 32° F. as the temperature of the mercurial column, and 62° F. as that of the metal scale; it is therefore important to make this reduction, as well as that for instrumental error (art. 57), in order to be enabled to compare the true barometric pressure with the normal that may be expected for any locality. The following table gives the value of this correction for each 2° F., the plus sign showing that the correction is to be added to the reading of the ship's barometer and the minus sign that it is to be subtracted:

Temperature.	Correction.	Temperature.	Correction.	Temperature.	Correction.	Temperature.	Correction.
°	*Inch.*	°	*Inch..*	°	*Inch.*	°	*Inch.*
20	+0. 02	40	−0. 03	60	−0. 09	80	−0. 14
22	+0. 02	42	−0. 04	62	−0. 09	82	−0. 14
24	+0. 01	44	−0. 04	64	−0. 09	84	−0. 15
26	+0. 01	46	−0. 05	66	−0. 10	86	−0. 15
28	0. 00	48	−0. 05	68	−0. 10	88	−0. 16
30	0. 00	50	−0. 06	70	−0. 11	90	−0. 16
32	−0. 01	52	−0. 06	72	−0. 12	92	−0. 17
34	−0. 02	54	−0. 07	74	−0. 12	94	−0. 17
36	−0. 02	56	−0. 07	76	−0. 13	96	−0. 18
38	−0. 03	58	−0. 08	78	−0. 13	98	−0. 18

As an example, let the observed reading of the mercurial barometer be 29.95 inches, and the temperature as given by the attached thermometer 74°; then we have:

	″
Observed height of the mercury	29.95
Correction for temperature (74°)	—0.12
Height of the mercury at standard temperature	29.83

56. The Aneroid Barometer.—This is an instrument in which the pressure of the air is measured by means of the elasticity of a plate of metal. It consists of a cylindrical brass box, the metal in the sides being very thin; the contained air having been partially, though not completely, exhausted, the box is hermetically sealed. When the pressure of the atmosphere increases the inclosed air is compressed, the capacity of the box is diminished, and the two flat ends approach each other; when the pressure of the atmosphere decreases, the ends recede from one another in consequence of the expansion of the inclosed air. By means of a combination of levers, this motion of the ends of the box is communicated to an index pointer which travels over a graduated dial plate, the mechanical arrangement being such that the motion of the ends of the box is magnified many times, a very minute movement of the box making a considerable difference in the indication of the pointer. The graduations of the aneroid scale are obtained by comparison with the correct readings of a standard mercurial barometer under normal and reduced atmospheric pressure.

The thermometer attached to the aneroid barometer is merely for convenience in indicating the temperature of the air, but as regards the instrument itself no correction for temperature can be applied with certainty. Aneroids, as now manufactured, are almost perfectly compensated for temperature by the use of different metals having unequal coefficients of expansion; they ought, therefore, to show the same pressure at all temperatures.

The aneroid barometer, from its small size and the ease with which it may be transported, can often be usefully employed under circumstances where a mercurial barometer would not be available. It also has an advantage over the mercurial instrument in its greater sensitiveness, and the fact that it gives earlier indications of change of pressure. It can, however, be relied upon only when frequently compared with a standard mercurial barometer; moreover, considerable care is required in its handling; while slight shocks will not ordinarily affect it, a severe jar or knock may change its indications by a large amount.

When in use the aneroid barometer may be suspended vertically or placed flat, but changing from one position to another ordinarily makes a sensible change in the readings; the instrument should always, therefore, be kept in the same position, and the errors determined by comparisons made while occupying its customary place.

57. Comparison of Barometers.—To determine the reliability of the ship's barometer, whether mercurial or aneroid, comparisons should from time to time be made with a standard barometer. Nearly all instruments read either too high or too low by a small amount. These errors arise, in a mercurial barometer, from the improper placing of the scale, lack of uniformity of caliber of the glass tube, or similar causes; in an aneroid, which is less accurate and in which there is even more necessity for frequent comparisons, errors may be due to derangement of any of the various mechanical features upon which its working depends. The errors of the barometer should be determined for various heights, as they are seldom the same at all parts of the scale.

In the principal ports of the world standard barometers are observed at specified times each day, and the readings, reduced to zero and to sea level, are published. It is therefore only necessary to read the barometer on shipboard at those times and, if a mercurial instrument is used, to note the attached thermometer and apply the correction for temperature (art. 55). It is evident that a comparison of the heights by reduced standard and by the ship's barometer will give the correction to be applied to the latter, including the instrumental error, the reduction to sea level, and the personal error of the observer. In the United States, standard barometer readings are made by the Weather Bureau.

Aneroid barometers may be adjusted for instrumental error by moving the index hand, but this is usually done only in the case of errors of considerable magnitude.

58. Determination of Heights by Barometer.—The barometer may be used to determine the difference in heights between any two stations by means of the difference in atmospheric pressure between them. An approximate rule is to allow 0.0011 inch for each difference in level of 1 foot, or, more roughly, 0.01 inch for every 9 feet.

A very exact method is afforded by Babinet's formula. If B_0 and B represent the barometric pressure (corrected for all sources of instrumental error) at the lower and at the upper stations respectively, and t_0 and t the corresponding temperatures of the air; then,

$$\text{Diff. in height} = C \times \frac{B_0 - B}{B_0 + B};$$

if the temperatures be taken by a Fahrenheit thermometer,

$$C \text{ (in feet)} = 52,494 \left(1 + \frac{t_0 + t - 64}{900}\right);$$

if a centigrade thermometer is used,

$$C \text{ (in meters)} = 16,000\left(1 + \frac{2(t_0 + t)}{1000}\right).$$

THE THERMOMETER.

59. The *Thermometer* is an instrument for indicating temperature. In its construction advantage is taken of the fact that bodies are expanded by heat and contracted by cold. In its most usual form the thermometer consists of a bulb filled with mercury, connected with a tube of very fine cross-sectional area, the liquid column rising or falling in the tube according to the volume of the mercury due to the actual degree of heat, and the height of the mercury indicating upon a scale the temperature; the mercury contained in the tube moves in a vacuum produced by the expulsion of the air through boiling the mercury and then closing the top of the tube by means of the blowpipe.

There are three classes of thermometer, distinguished according to the method of graduating the scale as follows: the *Fahrenheit*, in which the freezing point of water is placed at 32° and its boiling point (under normal atmospheric pressure) at 212°; the *Centigrade*, in which the freezing point is at 0° and the boiling point at 100°; and the *Réaumur*, in which these points are at 0° and 80°, respectively. The Fahrenheit thermometer is generally used in the United States and England. Tables will be found in this work for the interconversion of the various scale readings (Table 31).

60. The thermometer is a valuable instrument for the mariner, not only by reason of the aid it affords him in judging meteorological conditions from the temperature of the air and the amount of moisture it contains, but also for the evidences it furnishes at times, through the temperature of the sea water, of the ship's position and the probable current that is being encountered.

61. The thermometers employed in determining the temperature of the air (wet and dry bulb) and of the water at the surface, should be mercurial, and of some standard make, with the graduation etched upon the glass stem; they should be compared with accurate standards, and not accepted if their readings vary more than 1° from the true at any point of the scale.

62. The dry-bulb thermometer gives the temperature of the free air. The wet-bulb thermometer, an exactly similar instrument, the bulb of which is surrounded by an envelope of moistened cloth, gives what is known as the *temperature of evaporation,* which is always somewhat less than the temperature of the free air. From the difference of these two temperatures the observer may determine the proximity of the air to saturation; that is, how near the air is to that point at which it will be obliged to precipitate some of its moisture (water vapor) in the form of liquid. With the envelope of the wet bulb removed, the two thermometers should read precisely the same; otherwise they are practically useless.

The two thermometers, the wet and the dry bulb, should be hung within a few inches of each other, and the surroundings should be as far as possible identical. In practice the two thermometers[a] are generally inclosed within a small lattice case, such as that shown in figure 6; the case should be placed in a position on deck remote from any source of artificial heat, sheltered from the direct rays of the sun, and from the rain and spray, but freely exposed to the circulation of the air; the door should be kept closed except during the process of reading. The cloth envelope of the wet bulb should be a single thickness of fine muslin, tightly stretched over the bulb, and tied with a fine thread. The wick which serves to carry the water from the cistern to the bulb should consist of a few threads of lamp cotton, and should be of sufficient length to admit of two or three inches being coiled in the cistern. The muslin envelope of the wet bulb should be at all times thoroughly moist, but not dripping.

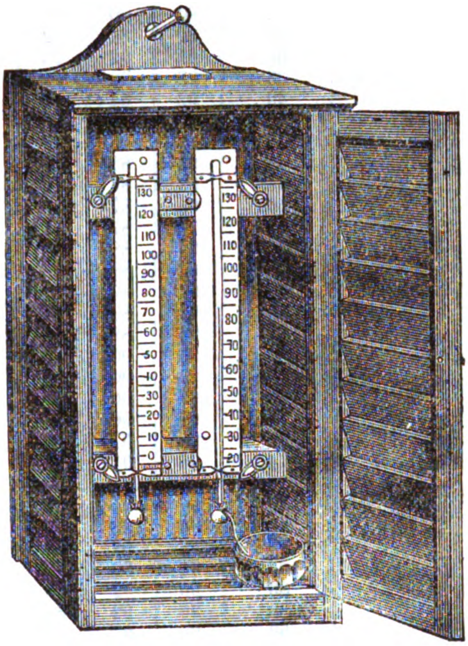

Fig. 6.

When the temperature of the air falls to 32° F. the water in the wick freezes, the capillary action is at an end, the bulb in consequence soon becomes quite dry, and the thermometer no longer shows the temperature of evaporation. At such times the bulb should be thoroughly wetted with ice-cold water shortly before the time of observation, using for this purpose a camel's hair brush or feather; by this process the temperature of the wet bulb is temporarily raised above that of the dry, but only for a brief time, as the water quickly freezes; and inasmuch as evaporation takes place from the surface of the ice thus formed precisely as from the surface of the water, the thermometer will act in the same way as if it had a damp bulb. The wet-bulb thermometer can not properly read higher than the dry, and if the reading of the wet bulb should be the higher, it may always be attributed to imperfections in the instruments.

[a] Called a psychrometer.

63. Knowing the temperature of the wet and dry bulbs, the relative humidity of the atmosphere at the time of observation may be found from the following table:

Temperature of the air, dry-bulb thermometer.	Difference between dry-bulb and wet-bulb readings.									
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
°	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
24	87	75	62	50	38	26				
26	88	76	65	53	42	30				
28	89	78	67	56	45	34	24			
30	90	79	68	58	48	38	28			
32	90	80	70	61	51	41	32	23		
34	90	81	72	63	53	44	35	27		
36	91	82	73	64	55	47	38	30	22	
38	92	83	75	66	57	50	42	34	26	
40	92	84	76	68	59	52	44	37	30	22
42	92	84	77	69	61	54	47	40	33	26
44	92	85	78	70	63	56	49	43	36	29
46	93	85	79	72	65	58	51	45	38	32
48	93	86	79	73	66	60	53	47	41	35
50	93	87	80	74	67	61	55	49	43	37
52	94	87	81	75	69	63	57	51	46	40
54	94	88	82	76	70	64	59	53	48	42
56	94	88	82	77	71	65	60	55	50	44
58	94	89	83	78	72	67	61	56	51	46
60	94	89	84	78	73	68	63	58	53	48
62	95	89	84	79	74	69	64	59	54	50
64	95	90	85	79	74	70	65	60	56	51
66	95	90	85	80	75	71	66	61	57	53
68	95	90	85	81	76	71	67	63	58	54
70	95	90	86	81	77	72	68	64	60	55
72	95	91	86	82	77	73	69	65	61	57
74	95	91	86	82	78	74	70	66	62	58
76	95	91	87	82	78	74	70	66	63	59
78	96	91	87	83	79	75	71	67	63	60
80	96	92	87	83	79	75	72	68	64	61
82	96	92	88	84	80	76	72	69	65	62
84	96	92	88	84	80	77	73	69	66	63
86	96	92	88	84	81	77	73	70	67	63
88	96	92	88	85	81	77	74	71	67	64
90	96	92	88	85	81	78	74	71	68	65

The table may be readily understood. For example, if the temperature of the air (dry bulb) be 60°, and the temperature of evaporation (wet bulb) be 56°, the difference being 4°, look in the column headed "Temperature of the air" for 60°, and for the figures on the same line in column headed 4°; here 78 will be found, which means that the air is 78 per cent saturated with water vapor; that is, that the amount of water vapor present in the atmosphere is 78 per cent of the total amount that it could carry at the given temperature (60°). This total amount, or saturation, is thus represented by 100, and if there occurred any increase of the quantity of vapor beyond this point, the excess would be precipitated in the form of liquid. Over the ocean's surface the relative humidity is generally about 90 per cent, or even higher in the doldrums; over the land in dry winter weather it may fall as low as 40 per cent.

64. The sea water of which the temperature is to be taken should be drawn from a depth of 3 feet below the surface, the bucket used being weighted in order to sink it. The bulb of the thermometer should remain immersed in the water at least three minutes before reading, and the reading should be made with the bulb immersed.

THE LOG BOOK.

65. The *Log Book* is a record of the ship's cruise, and, as such, an important accessory in the navigation. It should afford all the data from which the position of the ship is established by the method of dead reckoning; it should also comprise a record of meteorological observations, which should be made not only for the purpose of foretelling the weather during the voyage, but also for contribution to the general fund of knowledge of marine meteorology.

66. A convenient form for recording the data, which is employed for the log books of United States naval vessels, is shown on page 32; beside the tabulated matter thus arranged, to which one page of the book is devoted, a narrative of the miscellaneous events of the day, written and signed by the proper officers, appears upon the opposite page.

LOG OF THE UNITED STATES .... *RATE,*

....

Hour.	Knots.	Tenths.	Reading of patent log.	Average.		Reading of engine counter.	Courses steered by standard compass.	Wind.		Barometer.		Temperature.			State of the weather by symbols.	Clouds.			State of the sea.
				Steam.	Revolutions.			Direction by standard compass.	Force.	Height, in inches.	Thermometer attached.	Air, dry bulb.	Air, wet bulb.	Water at surface.		Forms of, by symbols.	Moving from.	Amount, scale 0 to 10.	
A. M.																			
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11																			
Noon.																			

8 a.m.	Latitude	....
8 a.m.	Longitude	....
Noon. D. R.	Latitude	....
Noon. D. R.	Longitude	....
Noon. Obs.	Latitude	....
Noon. Obs.	Longitude	....
Noon. Current	Set	....
Noon. Current	Drift	....
Noon. Made good	Distance	....
Noon. Made good	Course	....
8 p.m.	Latitude	....
8 p.m.	Longitude	....
Magazine temperatures:	Maximum	....
Magazine temperatures:	Minimum	....

Compass.	Error on course	....
Compass.	Variation	....
Compass.	Deviation	....
Coal.	Received	....
Coal.	Expended	....
Coal.	On hand	....
Fuel oil.	Received	....
Fuel oil.	Expended	....
Fuel oil.	On hand	....
Water.	Distilled	....
Water.	Received	....
Water.	Expended	....
Water.	On hand	....

Drills and exercises.

Morning.	*Afternoon.*
First division........	First division........
Second division........	Second division........
Third division........	Third division........
Fourth division........	Fourth division........
Fifth division........	Fifth division........
Sixth division........	Sixth division........
Seventh division........	Seventh division........
....	....
....	....
....	....

67. For the most part, the nature of the information called for, with the method of recording it, will be apparent. A brief explanation is here given of such points as seem to require it.

68. THE WIND.—In recording the force of the wind the scale devised by the late Admiral Sir F. Beaufort is employed. According to this scale the wind varies from 0, a calm, to 12, a hurricane, the greatest velocity it ever attains. In the lower grades of the scale the force of the wind is estimated from the speed imparted to a man-of-war of the early part of the nineteenth century sailing full and by; in the higher grades, from the amount of sail which the same vessel could carry when close-hauled. The scale, with the estimated velocity of the wind in both statute and nautical miles per hour, is as follows:

Force of wind.	Conditions.	Velocity.		Mean pressure in pounds per square foot.
		Statute miles per hour.	Nautical miles per hour.	
0.—Calm	Full-rigged ship, all sails set, no headway	0 to 3	0 to 2.6	0.03
1.—Light air	Just sufficient to give steerage way	8	6.9	0.23
2.—Light breeze	Speed of 1 or 2 knots, "full and by"	13	11.3	0.62
3.—Gentle breeze	Speed of 3 or 4 knots, "full and by"	18	15.6	1.2
4.—Moderate breeze	Speed of 5 or 6 knots, "full and by"	23	20.0	1.9
5.—Fresh breeze	All plain sail, "full and by"	28	24.3	2.9
6.—Strong breeze	Topgallant sails over single-reefed topsails	34	29.5	4.2
7.—Moderate gale	Double-reefed topsails	40	34.7	5.9
8.—Fresh gale	Treble-reefed topsails (or reefed upper topsails and courses).	48	41.6	8.4
9.—Strong gale	Close-reefed topsails and courses (or lower topsails and courses).	56	48.6	11.5
10.—Whole gale	Close-reefed main topsail and reefed foresail (or lower main topsail and reefed foresail).	65	56.4	15.5
11.—Storm	Storm staysails	75	65.1	20.6
12.—Hurricane	Under bare poles	90 and over.	78.1 and over.	29.6

69. When steaming or sailing with any considerable speed, the apparent direction and force of the wind, as determined from a vane flag, or pennant aboard ship, may differ materially from the true direction and force, the reason being that the air appears to come from a direction and with a force dependent, not only upon the wind itself, but also upon the motion of the vessel. For instance, suppose that the wind has a velocity of 20 knots an hour (force 4), and take the case of two vessels, each steaming 20 knots, the first with the wind dead aft, the second with the wind dead ahead. The former vessel will be moving with the same velocity as the air and in the same direction; the velocity of the wind relatively to the ship will thus be zero; on the vessel an apparent calm will prevail and the pennant will hang up and down. The latter vessel will be moving with the same velocity as the air, but in the opposite direction; the relative velocity of the two will thus be the sum of the two velocities, or 40 knots an hour, and on the second vessel the wind will apparently have the velocity corresponding very nearly with a fresh gale. Again, it might be shown that in the case of a vessel steaming west at the rate of 20 knots, with the wind blowing from north with the velocity of 20 knots an hour, the velocity with which the air strikes the ship as a result of the combined motion will be 28 knots an hour, and the direction from which it comes will be NW. If, therefore, the effect of the speed of the ship is neglected the wind will be recorded as NW., force 6, when in reality it is north, force 4.

In order to make a proper allowance for this error and arrive at the true direction and force of the wind, Table 32 may be entered with the ship's speed and the apparent direction and force of the wind as arguments, and the true direction and force will be found.

70. WEATHER.—To designate the weather a series of symbols devised by the late Admiral Beaufort is employed. The system employed in the United States Navy is as follows:

b.—Clear blue sky.
c.—Clouds.
d.—Drizzling, or light rain.
f.—Fog, or foggy weather.
g.—Gloomy, or dark, stormy-looking weather.
h.—Hail.
l.—Lightning.
m.—Misty weather.
o.—Overcast.
p.—Passing showers of rain.
q.—Squally weather.
r.—Rainy weather, or continuous rain.
s.—Snow, snowy weather, or snow falling.
t.—Thunder.
u.—Ugly appearances, or threatening weather.
v.—Variable weather.
w.—Wet, or heavy dew.
z.—Hazy weather.

To indicate great intensity of any feature, its symbol may be underlined; thus: *r.*, heavy rain.

71. CLOUDS.—The following are the principal forms of clouds, named in the order of the altitude above the earth at which they usually occur, beginning with the most elevated. The symbols by which each is designated follows its name:

1. CIRRUS (*Ci.*).—Detached clouds, delicate and fibrous looking, taking the form of feathers, generally of a white color, sometimes arranged in belts which cross a portion of the sky in great circles, and, by an effect of perspective, converging toward one or two opposite points of the horizon.

2. CIRRO-STRATUS (*Ci.-S.*).—A thin, whitish sheet, sometimes completely covering the sky and only giving it a whitish appearance, or at others presenting, more or less distinctly, a formation like a tangled web. This sheet often produces halos around the sun and moon.

3. CIRRO-CUMULUS (*Ci.-Cu.*).—Small globular masses or white flakes, having no shadows, or only very slight shadows, arranged in groups and often in lines.

4. ALTO-CUMULUS (*A.-Cu.*).—Rather large globular masses, white or grayish, partially shaded, arranged in groups or lines, and often so closely packed that their edges appear confused. The detached masses are generally larger and more compact at the center of the group; at the margin they form into finer flakes. They often spread themselves out in lines in one or two directions.

5. ALTO-STRATUS (*A.-S.*).—A thick sheet of a gray or bluish color, showing a brilliant patch in the neighborhood of the sun or moon, and which, without causing halos, may give rise to coronæ. This form goes through all the changes like the Cirro-Stratus, but its altitude is only half so great.

6. STRATO-CUMULUS (*S.-Cu.*).—Large globular masses or rolls of dark cloud, frequently covering the whole sky, especially in winter, and occasionally giving it a wavy appearance. The layer of Strato-Cumulus is not, as a rule, very thick, and patches of blue sky are often visible through the intervening spaces. All sorts of transitions between this form and the Alto-Cumulus are noticeable. It may be distinguished from Nimbus by its globular or rolled appearance and also because it does not bring rain.

7. NIMBUS (*N.*).—Rain clouds; a thick layer of dark clouds, without shape and with ragged edges, from which continued rain or snow generally falls. Through the openings of these clouds an upper layer of Cirro-Stratus or Alto-Stratus may almost invariably be seen. If the layer of Nimbus separates into shreds or if small loose clouds are visible floating at a low level underneath a large nimbus, they may be described as Fracto-Nimbus (Fr.-N.), the "scud" of sailors.

8. CUMULUS (*Cu.*).—Wool-pack clouds; thick clouds of which the upper surface is dome-shaped and exhibits protuberances, while the base is horizontal. When these clouds are opposite the sun the surfaces usually presented to the observer have a greater brilliance than the margins of the protuberances. When the light falls aslant, they give deep shadows; when, on the contrary, the clouds are on the same side as the sun, they appear dark, with bright edges. The true Cumulus has clear superior and inferior limits. It is often broken up by strong winds, and the detached portions undergo continual changes. These may be distinguished by the name of Fracto-Cumulus (*Fr.-Cu.*).

9. Cumulo-Nimbus (*Cu.-N.*).—The thunder-cloud or shower-cloud; heavy masses of clouds rising in the form of mountains, turrets, or anvils, generally having a sheet or screen of fibrous appearance above, and a mass of clouds similar to Nimbus underneath. From the base there usually fall local showers of rain or of snow (occasionally hail or soft hail).

10. Stratus (*S.*).—A horizontal sheet of lifted fog; when this sheet is broken up into irregular shreds by the wind or by the summits of mountains, it may be distinguished by the name of Fracto-Stratus (*Fr.-S.*).

72. In the scale for the amount of clouds 0 represents a sky which is cloudless and 10 a sky which is completely overcast.

73. State of Sea.—The state of the sea is expressed by the following system of symbols:

B.—Broken or irregular sea.
C.—Chopping, short, or cross sea.
G.—Ground swell.
H.—Heavy sea.
L.—Long rolling sea.
M.—Moderate sea or swell.
R.—Rough sea.
S.—Smooth sea.
T.—Tide-rips.

Note.—There are various publications issued by the Hydrographic Office dealing with special features of navigation, which should be regularly consulted. Among the most important of these are:

Pilot charts of the various oceans furnish information regarding the drift of derelicts, ice, and floating obstructions, the tracks of storms, average conditions of wind and weather, ocean currents, magnetic variation, etc.

Hydrographic Bulletin, weekly, gives more detailed facts than the Pilot Charts regarding ice, wrecks, and derelicts; also items on port facilities, use of oil to calm the sea, and miscellaneous items of use and interest to mariners.

Daily Memorandum, published at the main office at Washington, also makes public these items through the Branch Hydrographic Offices.

Notice to Mariners, weekly, gives changes in aids to navigation (lights, buoyage, harbor constructions), dangers to navigation (rocks, shoals, banks, bars), important new soundings, and, in general, all such facts as affect mariners' charts, manuals, and pilots or sailing directions.

CHAPTER III.

THE COMPASS ERROR.

CAUSES OF THE ERROR.

74. The properties of magnets are such that when two magnets are near enough together to exert a mutual influence, those poles which possess like magnetism repel each other, and those which possess unlike magnetism attract each other.

The earth is a magnetized body, and acts like a great spherical magnet with poles of unlike magnetism situated within the Arctic and Antarctic circles close to longitudes 97° west and 155° east of Greenwich, respectively. In common with magnets, the earth is surrounded by a region in which magnetic influence is exercised upon the compass, giving the magnetic needle a definite direction in each locality and causing the end which we name the north pole of the compass to be directed in general toward the region of the magnetic pole in the geographical north and the south end toward the region of the magnetic pole in the geographical south.

The north end of the compass—north-seeking, as it is sometimes designated for clearness—will be that end which has opposite polarity to the earth's north magnetic pole, or, otherwise stated, which possesses like magnetism with the earth's south magnetic pole.

75. By reason of the fact that the magnetic pole in each hemisphere differs in geographical position by a large and unequal amount from the geographical pole, we are made aware that the earth is not magnetized symmetrically with reference to the geographical poles. Hence the directive influence of the earth's magnetism will not in general cause the compass needle to point in the direction of the true meridian, but each compass point will differ from the corresponding true point by an amount varying according to the geographical locality. The angle representing this difference is the *Variation of the Compass*, sometimes also called the *Magnetic Declination*. It is the angle between the plane of the true meridian and a vertical plane passing through a freely suspended magnetic needle influenced solely by the earth's magnetism.

The variation not only changes as one travels from place to place on the earth, being different in different localities, but in every locality, besides the minor periodic movements of the needle known as the diurnal, monthly, and annual variations, which are not of material concern to the mariner, there is a progressive change which extends through centuries of time and amounts to large alterations in the pointing of the compass. In taking account of the effect produced by the variation of the compass, the navigator must therefore be sure that the variation used is correct not only for the *place*, but also for the *time* under consideration.

Occasionally the magnetic needle is subject to spasmodic fluctuations of the earth's magnetism lasting from a brief period to several days. These are called *magnetic storms*, and are due to sudden changes in the electric currents which circulate within the earth and in the region surrounding the earth. They come apparently at random, and may occur nearly simultaneously over the whole world or be restricted to a certain region. The range of their effect upon the compass does not often exceed the half of a degree in the lower latitudes, and hence the navigator need only be concerned with them in the higher latitudes where he may look to the aurora as an indication of their occurrence.

76. Besides the error thus produced in the indications of the compass, a further one, due to *Local Attraction*, may arise from extraneous influences due to natural magnetic attraction in the vicinity of the vessel. Instances of this are quite common when a ship is in port, as she may be in close proximity to vessels, docks, machinery, or other masses of iron or steel. It is also encountered in the shallow waters of the sea in localities where the mineral substances in the earth itself possess magnetic qualities—as, for example, at certain places in Lake Superior and at others off the coast of Australia. When due to the last-named cause, it may be a source of great danger to the mariner, but, fortunately, the number of localities subject to local attraction is limited. The amount of this error can seldom be determined except by survey; if known, it might properly be included with the variation and treated as a part thereof.

77. In addition to the variation, the compass ordinarily has a still further error in its indications, which arises from the effect exerted upon it by masses of magnetic metal within the ship itself. This is known as the *Deviation of the Compass.* For reasons that will be explained later, it differs in amount for each heading of the ship, and, further, the character of the deviations undergoes modification as a vessel proceeds from one geographical locality to another.

APPLYING THE COMPASS ERROR.

78. From what has been explained, it may be seen that there are three methods by which bearings or courses may be expressed: (*a*) *true,* when they refer to the angular distance from the earth's geographical meridian; (*b*) *magnetic,* when they refer to the angular distance from the earth's magnetic meridian, and must be corrected for variation to be converted into true; and (*c*) *by compass,* when they refer to the angular distance from the north indicated by the compass on a given heading of the ship, and must be corrected for the deviation on that heading for conversion to magnetic, and for both deviation and variation for conversion to true bearings or courses. The process of applying the errors under all circumstances is one of which the navigator must make himself a thorough master; the various problems of conversion are constantly arising; no course can be set nor bearing plotted without involving the application of this problem, and a mistake in its solution may produce serious consequences. The student is therefore urged to give it his most careful attention.

79. When the effect of a compass error, whether arising from variation or from deviation, is to draw the north end of the compass needle to the right, or eastward, the error is named *east,* or is marked +; when its effect is to draw the north end of the needle to the left or westward, it is named *west,* or marked −.

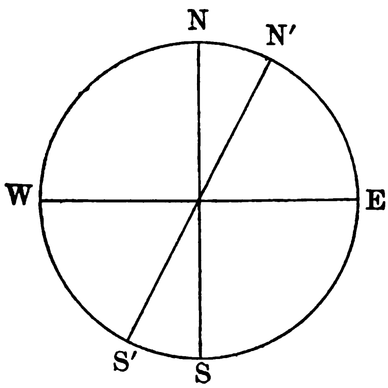

FIG. 7.

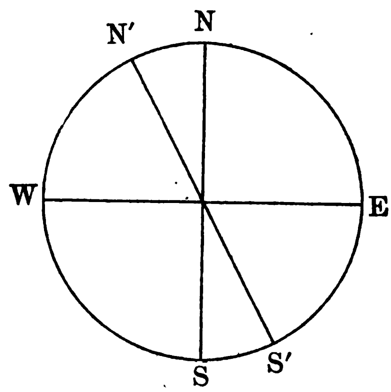

FIG. 8.

Figures 7 and 8 represent, respectively, examples of easterly and westerly errors. In both cases consider that the circles represent the observer's horizon, N and S being the correct north and south points in each case. If N′ and S′ represent the corresponding points indicated by a compass whose needle is deflected by a compass error, then in the first case, the north end of the needle being drawn to the right or east, the error will be easterly or positive, and in the second case, the north end of the needle being drawn to the left or west, the compass error will be westerly or negative.

Considering figure 7, if we assume the easterly error to amount to one point, it will be seen that if a direction of N. by W. is indicated by the compass, the correct direction should be north, or one point farther to the right. If the compass indicates north, the correct bearing is N. by E.; that is, still one point to the right. If we follow around the whole card, the same relation will be found in every case, the corrected bearing being always one point to the right of the compass bearing. Conversely, if we regard figure 8, assuming the same amount of westerly error, a compass bearing of N. by E. is the equivalent of a correct bearing of north, which is one point to the left; and this rule is general throughout the circle, the corrected direction being always to the left of that shown by the compass.

80. Having once satisfied himself that the general rule holds, the navigator may save the necessity of reasoning out in each case the direction in which the error must be applied, and need only charge his mind with some single formula which will cover all cases. Such a one is the following:

When the CORRECT *direction is to the* RIGHT, *the error is* EAST.

The words *correct-right-east*, in such a case, would be the key to all of his solutions. With easterly error, if he had a compass course to change to a corrected one, he would know that to obtain the result the error must be applied to the right; and, if it were desired to change a correct course to one indicated by compass, the error would be applied to the left. If a correct bearing is to be compared with a compass bearing to find the compass error, when the correct bearing is to the right, the error is easterly; and when the correct bearing is to the left, the error is westerly.

81. It must be remembered that the word *east* is equivalent to *right* in dealing with the compass error, and *west* to *left*, even though they involve an apparent departure from the usual rules. If a vessel steers NE. by compass with one point easterly error, her corrected course is NE. by E.; but if she steers SE., the corrected course is not SE. by E., but SE. by S. Another caution may be necessary to avoid confusion; the navigator should always regard himself as facing the point under consideration when he applies an error; one point westerly error on South will bring a corrected direction to S. by E.; but if we applied one point to the left of South while looking at the compass card in the usual way—north end up—S. by W. would be the point arrived at, and a mistake of two points would be the result.

82. In the foregoing explanation reference has been made to "correct" directions and "compass errors" without specifying "magnetic" and "true" or "variation" and "deviation." This has been done in order to make the statements apply to all cases and to enable the student to grasp the subject in its general bearing without confusion of details.

Actually, as has already been pointed out, directions given may be true, magnetic, or by compass. By applying variation to a magnetic bearing we correct it and make it true, by applying a deviation to a compass bearing we correct it to magnetic, and by applying to it the combined deviation and variation we correct it to true. Whichever of these operations is undertaken, and whichever of the errors is considered, the process of correction remains the same; the correct direction is always to the right, when the error is east, by the amount of that error.

Careful study of the following examples will aid in making the subject clear:

EXAMPLES: A bearing taken by a compass free from deviation is 76°; variation, 5° W.; required the true bearing. 71°.

A bearing taken by a similar compass is NW. by W. ½ W.; variation, ¼ pt. W.; required the true bearing. NW. by W. ¾ W.

A vessel steers 153° by compass; deviation on that heading, 3° W.; variation in the locality, 12° E.; required the true course. 162°.

A vessel steers S. by W. ½ W.; deviation, ¼ pt. W.; variation, 1 pt. E.; required the true course. SSW. ¼ W.

It is desired to steer the magnetic course 322°; deviation, 4° E.; required the course by compass. 318°.

The true course between two points is found to be W. ⅞ N.; variation, 1¼ pt. E.; no deviation; required the compass course. W. ⅜ S.

True course to be made, 55°; deviation, 7° E.; variation, 14° W.; required the course by compass. 62°.

A vessel passing a range whose direction is known to be 200°, magnetic, observes the bearing by compass to be 178°; required the deviation. 22° E.

The sun's observed bearing by compass is 91°; it is found by calculation to be 84° (true); variation, 8° W.; required the deviation. 1° E.

FINDING THE COMPASS ERROR.

83. The variation of the compass for any given locality is found from the charts. A nautical chart always contains information from which the navigator is enabled to ascertain the variation for any place within the region embraced and for any year. Beside the information thus to be acquired from local charts, special charts are published showing the variation at all points on the earth's surface.

84. The deviation of the compass, varying as it does for every ship, for every heading, and for every geographical locality, must be determined by the navigator, for which purpose various methods are available.

Whatever method is used, the ship must be swung in azimuth and an observation made on each of the headings upon which the deviation is required to be known. If a new iron or steel ship is being swung for the first time, observations should be made on each of the twenty-four 15° rhumbs into which the compass card is divided. At later swings, especially after correctors have been applied, or in the case of wooden ships, twelve 15° rhumbs will suffice—or, indeed, only six. In case it is not practicable to make observations on exact 15° rhumbs, they should be made as near thereto as practicable and plotted on the Napier diagram (to be explained hereafter), whence the deviations on exact 15° rhumbs may be found.

85. In swinging ship for deviations the vessel should be on an even keel and all movable masses of iron in the vicinity of the compass secured as for sea, and the compass accurately centered in the binnacle. The vessel, upon being placed on any heading, should be steadied there for three or four minutes before the observation is made, in order that the compass card may come to rest and the magnetic conditions assume a settled state. To assure the greatest accuracy the ship should first be swung to starboard, then to port, and the mean of the two deviations on each course taken. Ships may be swung under their own steam, or with the assistance of a tug, or at anchor, where the action of the tide tends to turn them in azimuth (though in this case it is difficult to get them steadied for the requisite time on each heading), or at anchor, by means of springs and hawsers.

86. The deviation of all compasses on the ship may be obtained from the same swing, it being required to make observations with the standard only. To accomplish this it is necessary to record the ship's head by all compasses at the time of steadying on each even rhumb of the standard; applying the deviation, as ascertained, to the heading by standard, gives the magnetic heads, with which the direction of the ship's head by each other compass may be compared, and the deviation thus obtained. Then a complete table of deviations may be constructed as explained in article 94.

87. There are four methods for ascertaining the deviations from swinging; namely, by *reciprocal bearings*, by *bearings of the sun*, by *ranges*, and by a *distant object*.

88. Reciprocal Bearings.—One observer is stationed on shore with a spare compass placed in a position free from disturbing magnetic influences; a second observer is at the standard compass on board ship. At the instant when ready for observation a signal is made, and each notes the bearing of the other. The bearing by the shore compass, reversed, is the magnetic bearing of the shore station from the ship, and the difference between this and the bearing by the ship's standard compass represents the deviation of the latter.

In determining the deviations of compasses placed on the fore-and-aft amidship line, when the distribution of magnetic metal to starboard and port is symmetrical, the shore compass may be replaced by a dumb compass, or pelorus, or by a theodolite in which, for convenience, the zero of the horizontal graduated circle may be termed north; the reading of the shore instrument will, of course, not represent magnetic directions, but by assuming that they do we obtain a series of fictitious deviations, the mean value of which is the error common to all. Upon deducting this error from each of the fictitious deviations, we obtain the correct values.

If ship and shore observers are provided with watches which have been compared with one another, the times may be noted at each observation, and thus afford a means of locating errors due to misunderstanding of signals.

89. Bearings of the Sun.—In this method it is required that on each heading a bearing of the sun be observed by compass and the time noted at the same moment by a chronometer or watch. By means which will be explained in Chapter XIV, the true bearing of the sun may be ascertained from the known data, and this, compared with the compass bearing, gives the total compass error; deducting from the compass error the variation, there remains the deviation. The variation used may be that given by the chart, or, in the case of a compass affected only by symmetrically placed iron or steel, may be considered equal to the mean of all the total errors. Other celestial bodies may be observed for this purpose in the same manner as the sun.

This method is important as being the most convenient one available for determining the compass error at sea. When adjusting compasses much time will be saved by this simple modification of a detail:

Instead of tabulating magnetic azimuths for given stated times in advance, draw on cross-section paper a curve whose ordinates are minutes of local apparent time and whose abscissæ are degrees of magnetic azimuth, that is, true azimuth corrected for variation. Then for any given instant (the navigator's watch being set to local apparent time) the magnetic azimuth may be read directly from the curve. The difference between the magnetic azimuth of the sun and its compass bearing is, of course, the deviation of the compass on that particular heading.

90. Ranges.—In many localities there are to be found natural or artificial range marks which are clearly distinguishable, and which when in line lie on a known magnetic bearing. By steaming about on different headings and noting the compass bearing of the ranges each time of crossing the line that they mark, a series of deviations may be obtained, the deviation of each heading being equal to the difference between the compass and the magnetic bearing.

91. Distant Object.—A conspicuous object is selected which must be at a considerable distance from the ship and upon which there should be some clearly defined point for taking bearings. The direction of this object by compass is observed on successive headings. Its true or magnetic bearing is then found and compared with the compass bearings, whence the deviation is obtained.

The true or the magnetic bearing may be taken from the chart. The magnetic bearing may also be found by setting up a compass ashore, free from foreign magnetic disturbance, in range with the object and the ship, and observing the bearing of the object; or the magnetic bearing may be assumed to be the mean of the compass bearings.

In choosing an object for use in this method care must be taken that it is at such a distance that its bearing from the ship does not practically differ as the vessel swings in azimuth. If the ship is swung at anchor, the distance should be not less than 6 miles. If swung under way, the object must be so far that the parallax (the tangent of which may be considered equal to half the diameter of swinging divided by the distance) shall not exceed about 30′.

92. In all of the methods described it will be found convenient to arrange the results in tabular form. In one column record the ship's head by standard compass, and abreast it in successive columns the observations from which the deviation is determined on that heading, and finally write the deviation itself. When the result of the swing has been worked up, another table is constructed showing simply the headings and the corresponding deviations. This is known as the *Deviation Table* of the compass. If compensation is to be attempted, this table is the basis of the operation; if not, the deviation tables of the standard and steering compass should be posted in such place as to be accessible to all persons concerned with the navigation of the ship.

93. Let it be assumed that a deviation table has been found and that the values are as follows:

Deviation table.

Ship's head by standard compass.		Deviation.		Ship's head by standard compass.		Deviation.	
	°	°	′		°	°	′
North	0	−15	29	South	180	+17	52
	15	−14	53		195	+23	47
	30	−13	16		210	+27	07
NE	45	−11	19	SW	225	+25	35
	60	− 9	59		240	+21	57
	75	− 9	42		255	+15	54
East	90	− 9	06	West	270	+ 9	56
	105	− 9	01		285	+ 1	56
	120	− 7	51		300	− 4	09
SE	135	− 5	54	NW	315	−10	20
	150	− 2	16		330	−13	37
	165	+ 8	29		345	−16	01

We have from the table the amount of deviation on each compass heading; therefore, knowing the ship's head by compass, it is easy to pick out the corresponding deviation and thus to obtain the magnetic heading. But if we are given the magnetic direction in which it is desired to steer and have to find the corresponding compass course, the problem is not so simple, for we are not given deviations on magnetic headings, and where the errors are large it may not be assumed that they are the same as on the corresponding compass headings. For example, with the deviation table just given, suppose it is required to determine the compass heading corresponding to 165°, magnetic.

The deviation corresponding to 165°, per compass, is +8½°. If we apply this to 165°, magnetic, we have 156½° as the compass course. But, consulting the table, it may be seen that the deviation corresponding to 156½°, per compass, is +2½°, and therefore if we steer that course the magnetic direction will be 159°, and not 165°, as desired.

A way of arriving at the correct result is to make a series of trials until a course is arrived at which fulfills the conditions. Thus, in the example given:

First trial.

Mag. course desired	165°
Try dev. on 165°	8½° E.
Trial comp. course	156½°
Dev. on 156½°	2½° E.
Mag. course made good	159°

Since this assumption carries the course 6° too far to the left, assume next a deviation on a course 3½° farther to the right than the one used here.

Second trial.

Mag. course desired	165°
Try dev. on 160°	5° E.
Trial comp. course	160°
Dev. on 160°	5°
Mag. course made good	165°

This happens to be exactly the compass course required. But it often occurs that further trials may be necessary.

94. The Napier Diagram.—A much more expeditious method for the solution of this problem is afforded by the *Napier Diagram,* and as that diagram also facilitates a number of other operations connected with compass work it should be clearly understood by the navigator. This admits of a graphic representation of the table of deviations of the compass by means of a curve; besides furnishing a ready means of converting compass into magnetic courses and the reverse, one of its chief merits is that if the deviation has been determined on a certain number of headings it enables one to obtain the most probable value of the deviation on any other course that the ship may head. The last-named feature renders it useful in making a table of deviations of compasses other than the standard when their errors are found as described in article 86.

95. The Napier diagram (fig. 9) represents the margin of a compass card cut at the north point and straightened into a vertical line; for convenience, it is usually divided into two sections, representing, respectively, the eastern and western semicircles. The vertical line is of a convenient length and divided into twenty-four equal parts corresponding to the 15° rhumbs of the compass, beginning at the top with North and continuing around to the right; it is also divided into 360 degrees, which are appropriately marked.

To obtain a complete curve, a sufficient number of observations should be taken while the ship swings through an entire circle. Generally, observations on every alternate 15° rhumb are enough to establish a good curve, but in cases where the maximum deviation reaches 40° it is preferable to observe on every 15° rhumb.

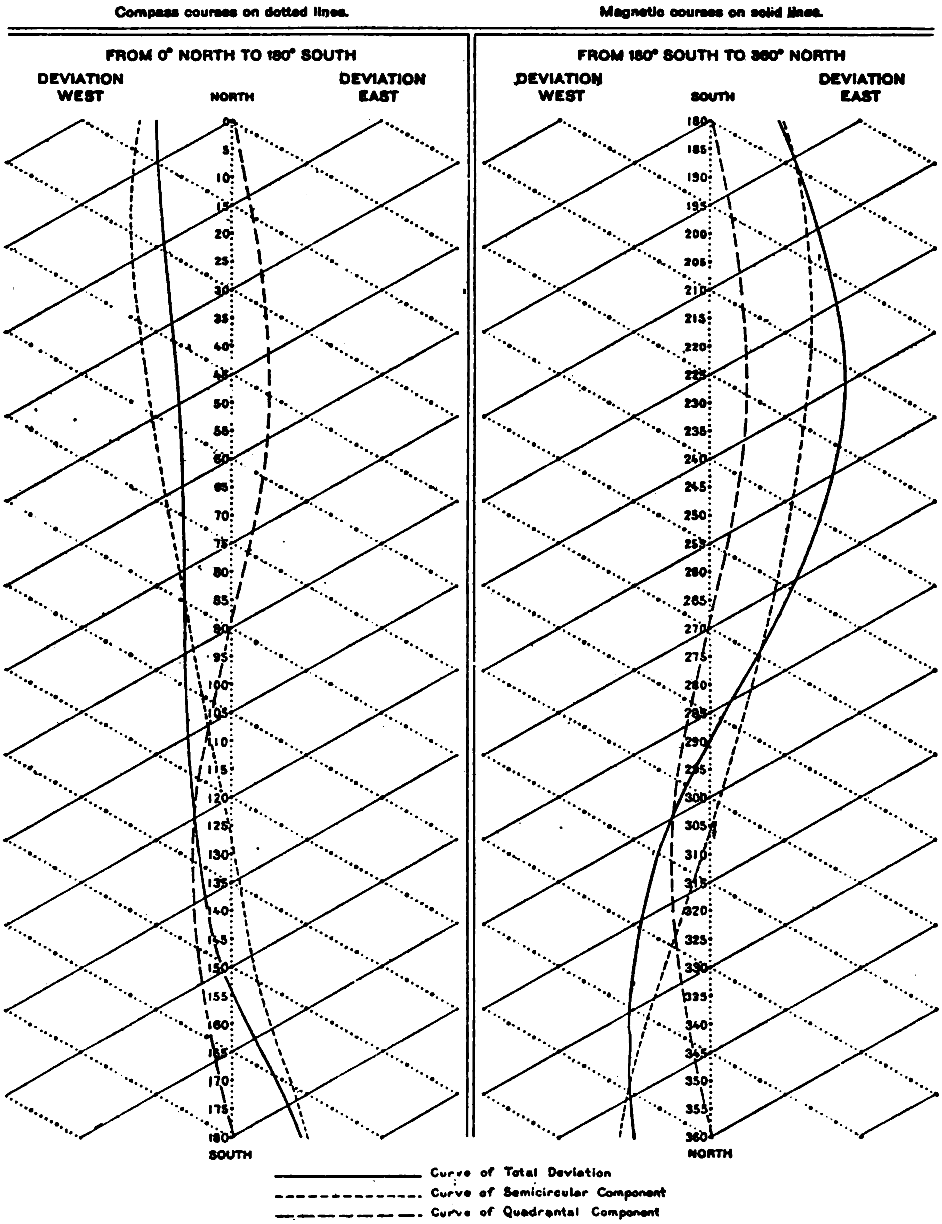

FIG. 9.

The curve shown in the full line on figure 9 corresponds to the table of deviations given in article 93.

From a given compass course to find the corresponding magnetic course, through the point of the vertical line representing the given compass course draw a line parallel to the *dotted* lines until the curve is intersected, and from the point of intersection draw another line parallel to the plain lines; the point on the scale where this last line cuts the vertical line is the magnetic course sought. The correctness of this solution will be apparent when we consider that the 60° triangles are equilateral, and therefore the distance measured along the vertical side will equal the distance measured along the inclined sides—that is, the deviation; and the direction will be correct, for the construction is such that magnetic directions will be to the right of compass directions when the deviation is easterly and to the left if westerly.

From a given magnetic course to find the corresponding compass course, the process is the same, excepting that the first line drawn should follow, or be parallel to, the *plain* lines, and the second, or return line, should be parallel to the dotted; and a proof similar to that previously employed will show the correctness of the result. As an example, the problem given in article 93 may be solved by the diagram, and the result will be found to accord with the solution previously given.

The vertical line is intersected at each 15° rhumb by two lines inclined to it at an angle of 60°, that line which is inclined upward to the right being drawn plain and the other dotted.

To plot a curve on the Napier diagram, if the deviation has been observed with the ship's head on given *compass* courses (as is usually the case with the standard compass), measure off on the vertical scale the number of degrees corresponding to the deviation and lay it down—to the right if easterly and to the left if westerly—on the *dotted* line passing through the point representing the ship's head; or, if the observation was not made on an even 15° rhumb, then lay it down on a line drawn parallel to the dotted ones through that division of the vertical line which represents the compass heading; if the deviation has been observed with the ship on given *magnetic* courses (as when deviations by steering compass are obtained by noting the ship's head during a swing on even 15° rhumbs of the standard), proceed in the same way, excepting that the deviation must be laid down on a *plain* line or a line parallel thereto. Mark each point thus obtained with a dot or small circle, and draw a free curve passing, as nearly as possible, through all the points.

THE THEORY OF DEVIATION.[a]

96. Features of the Earth's Magnetism.—It has already been stated that the earth acts like a great spherical magnet, with a pole in each hemisphere which is not coincident with the geographical pole; it has also a magnetic equator which lies close to, but not coincident with, the geographical equator.

A magnetic needle freely suspended at a point on the earth's surface, and undisturbed by any other than the earth's magnetic influence, will lie in the plane of the magnetic meridian and at an angle with the horizon depending upon the geographical position.

The magnetic elements of the earth which must be considered are shown in figure 10. The earth's *total force* is represented in direction and intensity by the line AB. Since compass needles are mechanically arranged to move only in a horizontal plane, it becomes necessary, when investigating the effect of the earth's magnetism upon them, to resolve the total force into two components which in the figure are represented by AC and AD. These are known, respectively, as the *horizontal* and *vertical components* of the earth's total force, and are usually designated as H and Z. The angle CAB, which the line of direction makes with the plane of the horizon, is called the *magnetic inclination* or *dip,* and denoted by θ.

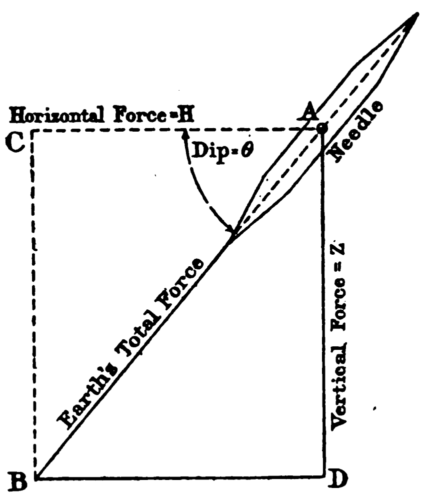

Fig. 10.

It is clear that the horizontal component will reduce to zero at the magnetic poles, where the needle points directly downward, and that it will reach a maximum

[a] As it is probable that the student will not have practical need of a knowledge of the theory of deviation and the compensation of the compass until after he has mastered all other subjects pertaining to Navigation and Nautical Astronomy, it may be considered preferable to omit the remainder of this chapter at first and return to it later.

at the magnetic equator, where the free needle hangs in a horizontal direction. The reverse is true of the vertical component and of the angle of dip.

Values representing these different terms may be found from special charts.

97. Induction; Hard and Soft Iron.—When a piece of unmagnetized iron or steel is brought within the influence of a magnet, certain magnetic properties are immediately imparted to the former, which itself becomes magnetic and continues to remain so as long as it is within the sphere of influence of the permanent magnet; the magnetism that it acquires under these circumstances is said to be *induced*, and the properties of *induction* are such that that end or region which is nearest the pole of the influencing magnet will take up a polarity opposite thereto. If the magnet is withdrawn, the induced magnetism is soon dissipated. If the magnet is brought into proximity again, but with its opposite pole nearer, magnetism will again be induced, but this time its polarity will be reversed. A further property is that if a piece of iron or steel, while temporarily possessed of magnetic qualities through induction, be subjected to blows, twisting, or mechanical violence of any sort, the magnetism is thus made to acquire a permanent nature.

The softer the metal, from a physical point of view, the more quickly and thoroughly will induced magnetism be dissipated when the source of influence is withdrawn; hard metal, on the contrary, is slow to lose the effect of magnetism imparted to it in any way. Hence, in regarding the different features which affect deviation, it is usual to denominate as hard iron that which possesses retained magnetism of a stable nature, and as soft iron that which rapidly acquires and parts with its magnetic qualities under the varying influences to which it is subjected.

98. Magnetic Properties Acquired by an Iron or Steel Vessel in Building.—The inductive action of the earth's magnetism affects all iron or steel within its influence, and the amount and permanency of the magnetism so induced depends upon the position of the metal with reference to the earth's total force, upon its character, and upon the degree of hammering, bending, and twisting that it undergoes.

An iron bar held in the line of the earth's total force instantly becomes magnetic; if held at an angle thereto it would acquire magnetic properties dependent for their amount upon its inclination to the line of total force; when held at right angles to the line there would be no effect, as each extremity would be equally near the poles of the earth and all influence would be neutralized. If, while such a bar is in a magnetic state through inductive action, it should be hammered or twisted, a certain magnetism of a permanent character is impressed upon it, which is never entirely lost unless the bar is subjected to causes equal and opposite to those that produced the first effect.

A sheet of iron is affected by induction in a similar way, the magnetism induced by the earth diffusing itself over the entire plate and separating itself into regions of opposite polarity divided by a neutral area at right angles to the earth's line of total force. If the plate is hammered or bent, this magnetism takes up a permanent character.

If the magnetic mass has a third dimension, and assumes the form of a ship, a similar condition prevails. The whole takes up a magnetic character; there is a magnetic axis in the direction of the line of total force, with poles at its extremities and a zone of no magnetism perpendicular to it. The distribution of magnetism will depend upon the horizontal and vertical components of the earth's force in the locality and upon the direction of the keel in building; its permanency will depend upon the amount of mechanical violence to which the metal has been subjected by the riveting and other incidents of construction, and upon the nature of the metal employed.

99. Causes that Produce Deviation.—There are three influences that operate to produce deviation; namely, (*a*) *subpermanent magnetism;* (*b*) *transient magnetism induced in vertical soft iron*, and (*c*) *transient magnetism induced in horizontal soft iron.* Their effect will be explained.

Subpermanent magnetism is the name given to that magnetic force which originates in the ship while building, through the process explained in the preceding article; after the vessel is launched and has an opportunity to swing in azimuth, the magnetism thus induced will suffer material diminution until, after the lapse of a certain time, it will settle down to a condition that continues practically unchanged; the magnetism that remains is denominated subpermanent. The vessel will then approximate to a permanent magnet, in which the north polarity will lie in that region which was north in building and the south polarity (that which exerts an attracting influence on the north pole of the compass needle) in the region which was south in building.

Transient magnetism induced in vertical soft iron is that developed in the soft iron of a vessel through the inductive action of the vertical component only of the earth's total force, and is transient in nature. Its value or force in any given mass varies with and depends upon the value of the vertical component at the place, and is proportional to the sine of the dip, being a maximum at the magnetic pole and zero at the magnetic equator.

Transient magnetism induced in horizontal soft iron is that developed in the soft iron of a vessel through the inductive action of the horizontal component only of the earth's total force, and is transient in nature. Its value or force in any given mass varies with and depends upon the value of the horizontal component at the place, and is proportional to the cosine of the dip, being a maximum at the magnetic equator and reducing to zero at the magnetic pole.

The needle of a compass in any position on board ship will therefore be acted upon by the earth's total force, together with the three forces just described. The poles of these forces do not usually lie in the horizontal plane of the compass needle, but as this needle is constrained to act in a horizontal plane, its movements will be affected solely by the horizontal components of these forces, and its direction will be determined by the resultant of those components.

The earth's force operates to retain the compass needle in the plane of the magnetic meridian, but the resultant of the three remaining forces, when without this plane, deflects the needle, and the amount of such deflection constitutes the deviation.

100. CLASSES OF DEVIATION.—Investigation has developed the fact that the deviation produced as described is made up of three parts, which are known respectively as *semicircular*, *quadrantal*, and *constant* deviation, the latter being the least important. A clear understanding of the nature of each of these classes is essential for a comprehension of the methods of compensation.

101. *Semicircular Deviation* is that due to the combined influence, exerted in a horizontal plane, of the subpermanent magnetism of a ship and of the magnetism induced in soft iron by the vertical component of the earth's force. If we regard the effect of these two forces as concentrated in a single resultant pole exerting an attracting influence upon the north end of the compass needle, it may be seen that there will be some heading of the ship whereon that pole will lie due north of the needle and therefore produce no deviation; now consider that, from this position, the ship's head swings in azimuth to the right; throughout all of the semicircle first described an easterly deviation will be produced, and, after completing 180°, the pole will be in a position diameterically opposite to that from which it started, and will again exert no influence that tends to produce deviation. Continuing the swing, throughout the next semicircle the direction of the deviation produced will be always to the westward, until the circle is completed and the ship returns to her original neutral position. From the fact that this disturbing cause acts in the two semicircles with equal and opposite effect it is given the name of *semicircular* deviation.

In figure 9 a curve is depicted which shows the deviations of a semicircular nature separated from those due to other disturbing causes, and from this the reason for the name will be apparent.

102. Returning to the two distinct sources from which the semicircular deviation arises, it may be seen that the force due to subpermanent magnetism remains constant regardless of the geographical position of the vessel; but since the horizontal force of the earth, which tends to hold the needle in the magnetic meridian, varies with the magnetic latitude, the deviation due to subpermanent magnetism varies inversely as the horizontal force, or as $\frac{1}{H}$; this may be readily understood if it is considered that the stronger the tendency to cling to the direction of the magnetic meridian the less will be the deflection due to a given disturbing force. On the other hand, that part of the semicircular force due to magnetism induced in vertical soft iron varies as the earth's vertical force, which is proportional to the sine of the dip; its effect in producing deviation, as in the preceding case, varies inversely as the earth's horizontal force—that is, inversely as the cosine of the dip; hence the ratio representing the change of deviation arising from this cause on change of latitude is $\frac{\sin\theta}{\cos\theta}$, or $\tan\theta$.

If, then, we consider the change in the semicircular deviation due to a change of magnetic latitude, it will be necessary to separate the two factors of the deviation and to remember that the portion produced by subpermanent magnetism varies as $\frac{1}{H}$, and that due to vertical induction as $\tan\theta$. But for any consideration of the effect of this class of deviation in one latitude only, the two parts may be joined together and regarded as having a single resultant.

103. Assuming that all the forces tending to produce semicircular deviation are concentrated in a single pole exerting an influence on the north pole of the compass, it will be seen that this can be resolved into a horizontal and a vertical component, just as the earth's magnetic force is illustrated in figure 10. It is now evident, therefore, that the horizontal component of this single magnet may be resolved into two components—one fore-and-aft, and one athwartship; in this case, the semicircular forces will be represented by two magnets, one fore-and-aft and the other athwartship, and compensation may be made by two separate magnets lying respectively in the directions stated, but with their north or repelling poles in the position occupied by the south or attracting poles of the ship's force.

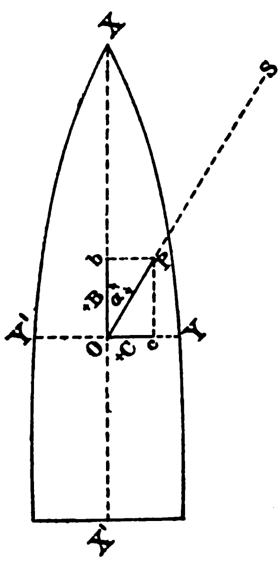

Fig. 11.

Figure 11 represents the conditions that have been described. Let O be the center of the compass, XX′ and YY′, respectively, the fore-and-aft and athwartship lines of the ship, and OS the direction in which the attracting pole of the disturbing force is exerted. Now, if OP be laid off on the line OS, representing the amount of the disturbing force according to some convenient scale, then O*b* and O*c*, respectively, represent, on the same scale, the resolved directions of that force in the keel line and in the transverse line of the ship. Each of these resolved forces will exert a maximum effect when acting at right angles to the needle, the athwartship one when the ship heads north or south by compass, and the longitudinal one when the heading is east or west. On any other heading than those named the deviation produced by each force will be a fraction of its maximum whose magnitude will depend upon the azimuth of the ship's head. The maximum deviation produced, therefore, forms in each case a basis for reckoning all of the various effects of the disturbing force, and is called a *coefficient*.

The coefficient of semicircular deviation produced by the force in the fore-and-aft line is called B, and is reckoned as positive when it attracts a north pole toward the bow, negative when toward the stern; that produced by the athwartship force is C, and is reckoned as positive to starboard and negative to port. These coefficients are expressed in degrees.[a]

104. The coefficient B is approximately equal to the deviation on East; or to the deviation on West with reversed sign; or to the mean of these two. Thus in the ship having the table of deviations previously given (art. 93), B is equal to $-9°\ 06'$, or to $-9°\ 56'$, or to $\frac{1}{2}\ (-9°\ 06'-9°\ 56')=-9°\ 31'$.

The coefficient C is approximately equal to the deviation on North; or to the deviation on South with reversed sign; or to the mean of these two. In the example C is equal to $-15°\ 29'$, or to $-17°\ 52'$, or to $\frac{1}{2}\ (-15°\ 29'-17°\ 52')=-16°\ 40'$.

[a] It should be remarked that in a mathematical analysis of the deviations, it would be necessary to distinguish between the *approximate coefficients*, B and C, here described, as also A, D, and E, to be mentioned later, and the *exact coefficients* denoted by the corresponding capital letters of the German alphabet, which latter are in reality the *forces* producing those deviations expressed in terms of the "mean force to north" (λH), as unit. In the practical discussion of the subject here given, the question of the difference need not be entered into further.

105. The value of the subpermanent magnetism remaining practically constant under all conditions, it will not alter when the ship changes her latitude; but that due to induction in vertical soft iron undergoes a change when, by change of geographical position, the vertical component of the earth's force assumes a different value, and in such case the correction by means of one or a pair of permanent magnets will not remain effective. If, however, by series of observations in two magnetic latitudes, the values of the coefficients can be determined under the differing circumstances, it is possible, by solving equations, to determine what effect each force has in producing the semicircular deviation; having done which, the subpermanent magnetism can be corrected by permanent magnets after the method previously described, and the vertical induction in soft iron can be corrected by a piece of vertical soft iron placed in such a position near the compass as to produce an equal but opposite force to the ship's vertical soft iron. This last corrector is called a *Flinders bar*.

Having thus opposed to each of the component forces a corrector of magnetic character identical with its own, a change of latitude will make no difference in the effectiveness of the compensation, for in every case the modified conditions will produce identical results in the disturbing and in the correcting force.

106. *Quadrantal Deviation* is that which arises from horizontal induction in the soft iron of the vessel through the action of the horizontal component of the earth's total force. Let us consider, in figure 12, the effect of any piece of soft iron which is symmetrical with respect to the compass—that is, which lies wholly within a plane passing through the center of the needle in either a fore-and-aft or an athwartship direction. It may be seen (*a*) that such iron produces no deviation on the cardinal points (for on north and south headings the fore-and-aft iron, though strongly magnetized, has no tendency to draw the needle from a north-and-south line, while the athwartship iron, being at right angles to the meridian, receives no magnetic induction, and therefore exerts no force; and on east and west headings similar conditions prevail, the athwartship and the fore-and-aft iron having simply exchanged positions); and (*b*) the direction of the deviation produced is opposite in successive quadrants. The action of unsymmetrical soft iron is not quite so readily apparent, but investigation shows that part of its effect is to produce a deviation which becomes zero at the inter-cardinal points and is of opposite name in successive quadrants. From the fact that deviations of this class change sign every 90° throughout the circle, they gain the name of *quadrantal deviations*. One of the curves laid down in the Napier diagram (fig. 9) is that of quadrantal deviations, whence the nature of this disturbance of the needle may be observed.

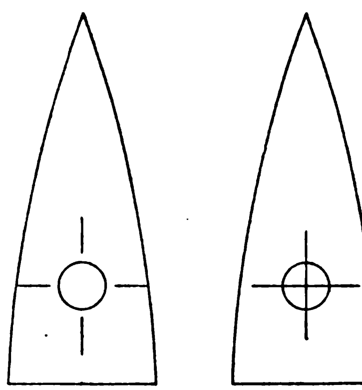

FIG. 12.

107. All deviations produced by soft iron may be considered as fractions of the maximum deviation due to that disturbing influence; and consequently the maximum is regarded as a coefficient, as in the case of semicircular deviations. The coefficient due to symmetrical soft iron is designated as D, and is considered positive when it produces easterly deviations in the quadrant between North and East; the coefficient of deviations arising from unsymmetrical soft iron is called E, and is reckoned as positive when it produces easterly deviations in the quadrant between NW. and NE.; this latter attains importance only when there is some marked inequality in the distribution of metal to starboard and to port, as in the case of a compass placed off the amidship line.

108. D is approximately equal to the mean of the deviations on NE. and SW.; or to the mean of those on SE. and NW., with sign reversed; or to the mean of those means. In the table of deviations given in article 93, D is equal to $\frac{1}{2}$ ($-11° 19' + 25° 35'$) $= +7° 08'$, or to $\frac{1}{2}$ ($+5° 54' + 10° 20'$) $= +8° 07'$; or to $\frac{1}{2}$ ($7° 08' + 8° 07'$) $= +7° 37'$. By reason of the nature of the arrangement of iron in a ship, D is almost invariably positive.

E is approximately equal to the mean of the deviations on North and South; or to the mean of those on East and West with sign reversed; or to the mean of those means. In the example, E is equal to ½ (−15° 29′+17° 52′) = +1° 11′; or to ½ (+9° 06′−9° 56′) = −0° 25′; or to ½ (+1° 11′−0° 25′) = +0° 23′.

109. Quadrantal deviation does not, like semicircular, undergo a change upon change of magnetic latitude; being due to induction in horizontal soft iron, the magnetic force exerted to produce it is proportional to the horizontal component of the earth's magnetism; but the directive force of the needle likewise depends upon that same component; consequently, as the disturbing force exerted upon the needle increases, so does the power that holds it in the magnetic meridian, with the result that on any given heading the deflection due to soft iron is always the same.

110. Quadrantal deviation is corrected by placing masses of soft iron (usually two hollow spheres in the athwartship line, at equal distances on each side of the compass), with the center of mass in the horizontal plane of the needle. The distance is made such that the force exerted exactly counteracts that of the ship's iron. As the correcting effect of this iron will, like the directive force and the quadrantal disturbing force, vary directly with the earth's horizontal component, the compensation once properly made will be effective in all latitudes; provided that the compass needles are short and, consequently, exercise little or no induction on the quadrantal correctors.

With compasses such as the United States Navy standard 7½-inch liquid compass, the needles of which are long and powerful, it will usually be found that the position of the spheres must be changed with change of latitude. This may be accounted for by the magnetism induced in the spheres by the compass needles at the same time and in the same manner as the earth's force. In this case the quadrantal correcting force is the resultant of the constant force due to the induction of the needles in the spheres and the variable force (the earth's horizontal force, H, varying with change in magnetic latitude) due to the induction of the earth in the spheres. This resultant of these two forces is a variable force, and, after a given quadrantal deviation is corrected in one latitude by this force, the balance will be changed upon going into another latitude and the correction will fail to hold good.

In practice, the quadrantal deviation due to unsymmetrical iron is seldom corrected; the correction may be accomplished, however, by placing the soft iron masses on a line which makes an angle to the athwartship line through the center of the card.

111. *Constant Deviation* is due to induction in horizontal soft iron unsymmetrically placed about the compass. It has already been explained that one effect of such iron is to produce a quadrantal deviation, represented by one coefficient E; another effect is the *constant* deviation, so called because it is uniform in amount and direction on every heading of the ship. If plotted on a Napier diagram, it would appear as a straight line parallel with the initial line of the diagram.

112. Like other classes of deviation, the effect of the disturbing force is represented by a coefficient; this coefficient is designated as A, and is considered *plus* for easterly and *minus* for westerly errors. It is approximately equal to the mean of the deviations on any number of equidistant headings. In the case previously given, it might be found from the four headings, North, East, South, and West, and would then be equal to ¼ (−15° 29′−9° 06′+17° 52′+9° 56′) = +0° 48′; or from all of the 24 headings, when it would equal −0° 01′.

For the same reason as in the case of E, the value of A is usually so small that it may be neglected; it only attains a material size when the compass is placed off the midship line, or for some similar cause.

113. Like quadrantal deviation, since its force varies with the earth's horizontal force, the constant deviation will remain uniform in amount in all latitudes. (See art. 110.)

No attempt is made to compensate for this class of error.

114. Coefficients.—The chief value of coefficients is in mathematical analyses of the deviations and their causes. It may, however, be a convenience to the practical navigator to find their approximate values by the methods that have been given, in order that he may gain an idea of the various sources of the error, with a view to ameliorating the conditions, when necessary, by moving the binnacle or altering the surrounding iron. The following relation exists between the coefficients and the deviation:

$$d = A + B \sin z' + C \cos z' + D \sin 2z' + E \cos 2z',$$

where d is the deviation, and z' the ship's heading by compass, measured from compass North.

115. Mean Directive Force.—The effect of the disturbing forces is not confined to causing deviations; it is only those components acting at right angles to the needle which operate to produce deflection; the effect of those acting in the direction of the needle is exerted either in increasing or diminishing the directive force of the compass, according as the resolved component is northerly or southerly.

It occurs, with the usual arrangement of iron in a vessel, that the mean effect of this action throughout a complete swing of the ship upon all headings is to reduce the directive force—that is, while it varies with the heading, the average value upon all azimuths is *minus* or southerly. The result of such a condition is unfavorable from the fact that the compass is thus made more "sluggish," is easily disturbed and does not return quickly to rest, and a given deflecting force produces a greater deviation when the directive force is reduced. The usual methods of compensation largely correct this fault, but do not entirely do so; it is therefore the case that the mean combined horizontal force of earth and ship to north is generally less than the horizontal force of the earth alone; but it is only in extreme cases that this deficiency is serious.

116. Heeling Error.—This is an additional cause of deviation that arises when the vessel heels to one side or the other. Heretofore only those forces have been considered which act when the vessel is on an even keel; but if there is an inclination from the vertical certain new forces arise, and others previously inoperative become effective. These forces are (*a*) the vertical component of the subpermanent magnetism acquired in building; (*b*) the vertical component of the induced magnetism in vertical soft iron, and (*c*) the magnetism induced by the vertical component of the earth's total force in iron which, on an even keel, was horizontal. The first two of these disturbing causes are always present, but, when the ship is upright, have no tendency to produce deviation, simply exerting a downward pull on one of the poles of the needle; the last is a new force that arises when the vessel heels.

The maximum disturbance due to heel occurs when the ship heads North or South. When heading East or West there will be no deviation produced, although the directive force of the needle will be increased or diminished. The error will increase with the amount of inclination from the vertical.

117. For the same reason as was explained in connection with semicircular deviations, that part of the heeling error due to subpermanent magnetism will vary, on change of latitude, as $\frac{1}{H}$, while that due to vertical induction will vary as $\tan \theta$. In south magnetic latitude the effect of vertical induction will be opposite in direction to what it is in north latitude.

118. The heeling error is corrected by a permanent magnet placed in a vertical position directly under the center of the compass. Such a magnet has no effect upon the compass when the ship is upright; but since its force acts in an opposite direction to the force of the ship which causes heeling error, is equal to the latter in amount, and is exerted under the same conditions, it affords an effective compensation. For similar reasons to those affecting the compensation of B and C, the correction by means of a permanent magnet is not general and must be rectified upon change of latitude.

PRACTICAL COMPENSATION.

119. In the course of explanation of the different classes of deviation occasion has been taken to state generally the various methods of compensating the errors that are produced. The practical methods of applying the correctors will next be given.

120. Order of Correction.—The following is the order of steps to be followed in each case. It is assumed that the vessel is on an even keel, that the compass is properly centered in the binnacle, that all surrounding masses of iron or steel are in their normal positions, all correctors removed, and that the binnacle is one in which the semicircular deviation is corrected by two sets of permanent magnets at right angles to each other.

In order to ascertain if the compass is properly centered in the binnacle, the heeling corrector may be temporarily placed in its tube and drawn from its lowest to its highest position; if no deflection is shown by the needle the compass is properly centered; if not it should be adjusted by the screws provided for the purpose.

1. Place quadrantal correctors by estimate.
2. Correct semicircular deviation.
3. Correct quadrantal deviation.
4. Swing ship for residual deviations.

The heeling corrector may be placed at any time after the semicircular and quadrantal errors are corrected. A Flinders bar can be put in place only after observations in two latitudes.

121. The ship is first placed on some magnetic cardinal point. If North or South, the only force (theoretically speaking) which tends to produce deflection of the needle will be the athwartship component of the semicircular force, whose effect is represented by the coefficient C. If East or West, the only deflecting force will be the fore-and-aft component of the semicircular force, whose effect is represented by the coefficient B. This will be apparent from a consideration of the direction of the forces producing deviation, and is also shown by the equation connecting the terms (where A and E are zero):

$$d = B \sin z' + C \cos z' + D \sin 2z'.$$

If the ship is headed North or South, z' being equal to 0° or 180°, the equation becomes $d = \pm C$. If on East or West, z' being 90° or 270°, we have $d = \pm B$.

This statement is exact if we regard only the forces that have been considered in the problem, but experience has demonstrated that the various correctors when in place create certain additional forces by their mutual action, and in order to correct the disturbances thus accidentally produced, as well as those due to regular causes, it is necessary that the magnetic conditions during correction shall approximate as closely as possible to those that exist when the compensation is completed; therefore the quadrantal correctors should first be placed on their arms at the positions which it is estimated that they will occupy later when exactly located. An error in the estimate will have but slight effect under ordinary conditions. It should be understood that the placing of these correctors has no corrective effect while the ship is on a cardinal point. Its object is to create at once the magnetic field with which we shall have to deal when compensation is perfected.

This having been done, proceed to correct the semicircular deviation. If the ship heads North or South, the force producing deflection is, as has been stated, the athwartship component of the semicircular force, which is to be corrected by permanent magnets placed athwartships; therefore enter in the binnacle one or more such magnets, and so adjust their height that the heading of the ship by compass shall agree with the magnetic heading. When this is done all the deviation on that azimuth will be corrected.

Similarly, if the ship heads East or West, the force producing deviation is the fore-and-aft component of the semicircular force, and this is to be corrected by entering fore-and-aft permanent magnets in the binnacle and adjusting the height so that the deviation on that heading disappears.

With the deviation on two adjacent cardinal points corrected, the semicircular force has been completely compensated. Next correct the quadrantal deviation. Head the ship NE., SE., SW., or NW. The coefficients B and C having been reduced to zero by compensation, and $2z'$, on the azimuths named, being equal to 90° or 270°, the equation becomes $d = \pm D$. The soft-iron correctors are moved in or out from the positions in which they were placed by estimate until the deviation on the heading (all of which is due to quadrantal force) disappears. The quadrantal disturbing force is then compensated.

122. Determination of Magnetic Headings.—To determine when a ship is heading on any given magnetic course, and thus to know when the deviation has been corrected and the correctors are in proper position, four methods are available:

(*a*) Swing the ship and obtain by the best available method the deviations on a sufficient number of compass courses to construct a curve on the Napier diagram for one quadrant, and thus find the compass headings corresponding to two adjacent magnetic cardinal points and the intermediate intercardinal point, as North, NE., and East, magnetic.[a] Then put the ship successively on these courses, noting the corresponding headings by some other compass, and when it is desired to head on the various magnetic azimuths during the process of correction the ship may be steadied upon them by the auxiliary compass. Variations of this method will suggest themselves and circumstances may render their adoption convenient. The compass courses corresponding to the magnetic directions may be obtained from observations made with the auxiliary compass itself, or while making observations with another compass the headings by the auxiliary may be noted and a curve for the latter constructed, as explained in article 95, and the required headings thus deduced.

(*b*) By the methods to be explained hereafter (Chap. XIV), ascertain in advance the true bearing of the sun at frequent intervals during the period which is to be devoted to the compensation of the compasses; apply to these the variation and obtain the magnetic bearings; record the times and bearings in a convenient tabular form, or, better still, plot a curve of magnetic azimuths of the sun on cross section paper, the coordinates being local apparent time and magnetic bearings of the sun, as described in article 89. Set the watch accurately for the local apparent time; then when it is required to steer any given magnetic course, set that point of the pelorus for the ship's head and set the sight vanes for the magnetic bearing of the sun corresponding to the time by watch. Maneuver the ship with the helm until the sun comes on the sight vanes, when the azimuth of the ship's head will be that which is required. The sight vanes must be altered at intervals to accord with the curve or table of times and bearings.

(*c*) Construct a curve or table showing times and corresponding magnetic bearings of the sun, and also set the watch, as explained for the previous method. Then place the sight vanes of the azimuth circle of the compass at the proper angular distance to the right or left of the required azimuth of the ship's head; leave them so set and maneuver the ship with the helm until the image of the sun comes on with the vanes. The course will then be the required one. As an example, suppose that the curve or table shows that the magnetic azimuth of the sun at the time given by the watch is N. 87° E., and let it be required to head magnetic North; when placed upon this heading, therefore, the sun must bear 87° to the right or east of the direction of the ship's head; when steady on any course, turn the sight vane to the required bearing relative to the keel. If on N. 11° W., for example, turn the circle to N. 76° E.; leave the vane undisturbed and alter course until the sun comes on. The magnetic heading is then North, and adjustment may be made accordingly.

(*d*) When ranges are available, they may be utilized for determining magnetic headings.

123. Summary of Ordinary Corrections.—To summarize, the following is the process of correcting a compass for a single latitude, where magnets at right angles are employed for compensating the semicircular deviation and where the disturbances due to unsymmetrical soft iron are small enough to be neglected.

First. All correctors being clear of the compass, place the quadrantal correctors in the position which it is estimated that they will occupy when adjustment is complete. The navigator's experience will serve in making the estimate, or if there seems no other means of arriving at the probable position they may be placed at the middle points of their supports.

Second. Steady the ship on magnetic north, east, south, or west, and hold on that heading by such method as seems best. By means of permanent magnets alter the indications of the compass until the heading coincides with the magnetic course. If heading north, magnets must be entered north ends to starboard to correct easterly deviation and to port to correct westerly, and the reverse if heading south. If heading east, enter north ends forward for easterly and aft for westerly deviations, and the reverse if heading west. (Binnacles differ so widely in the methods of carrying magnets that details on this point are omitted. It may be said, however, that

[a] This is all that is required for the purposes of compensation, but if there is opportunity it is always well to make a complete swing and obtain a full table of deviations, which may give interesting information of the existing magnetic conditions.

the magnetic intensity of the correctors may be varied by altering either their number or their distance from the compass; generally speaking, several magnets at a distance are to be preferred to a small number close to the compass.)

Third. Steady the ship on an adjacent magnetic cardinal point and correct the compass heading by permanent magnets to accord therewith in the same manner as described for the first heading.

Fourth. Steady the ship on an intercardinal point (magnetic) and move the quadrantal correctors away from or toward the compass, keeping them at equal distances therefrom, until the compass and magnetic headings coincide.

Fifth. If time permits, it is very important that the ship should next be steadied on opposite cardinal and semicardinal points and *one-half* of the remaining deviation corrected by changing the position or number of the correctors.

The compensation being complete, the navigator should proceed immediately to swing ship and make a table of the residual deviations. Though the remaining errors will be small, it is seldom that they will be reduced to zero, and it must never be assumed that the compass may be relied upon without taking the deviation into account. Observations on eight equidistant points will ordinarily suffice for this purpose.

124. COMPENSATION OF THE COMPASS WHILE CRUISING.—Every effort should be made to keep at least the standard and steering compasses compensated, as it is always easier to keep the compasses compensated than to keep a deviation table correct, at hand, and in use.

RECTANGULAR METHOD.

By the following method the compasses may be kept practically compensated and, after the data are once obtained, it requires very little time or trouble.

After the first compensation is completed, or while it is being done, head the ship north or south and move the athwartship magnets up exactly 1 inch, noting by the bearing of the sun or of a distant object, the amount and direction of the effect on the compass. Then repeat the observation, lowering the magnets 1 inch, and noting the effect. Then head the ship east or west and take the same observations with the fore-and-aft magnets. Then head on an intercardinal point and record the effect of moving spheres first in and then out an inch from the correct position.

The record would then take this form:

Date...... Latitude...... Longitude.......

H...... θ.......

On North, raising B magnets (6 bundles) 1 inch (from 9.85 to 8.85) causes 12° 30′ Easterly deviation, therefore a movement of $\frac{1}{10}$ inch causes 1° 15′ Ely.

Lowering B magnets (6 bundles) 1 inch (from 9.85 to 10.85) causes 10° 15′ Westerly deviation, therefore a movement of $\frac{1}{10}$ inch causes 1° 2′ Wly.

On East, raising C magnet (2 bundles) 1 inch (from 10.45 to 9.45) causes 8° 15′ Westerly deviation, therefore a movement of $\frac{1}{10}$ inch causes 0° 50′ Wly.

Lowering C magnet (2 bundles) 1 inch (from 10.45 to 11.45) causes 6° 30′ Easterly deviation, therefore a movement of $\frac{1}{10}$ inch causes 0° 39′ Ely.

On Northeast, moving spheres in 1 inch (from 10.6 to 9.6) causes 4° 15′ Westerly deviation, therefore a movement of $\frac{1}{10}$ inch causes 0° 25′ Wly.

Moving spheres out 1 inch (from 10.6 to 11.6) causes 3° 20′ Easterly deviation, therefore a movement of $\frac{1}{10}$ inch causes 0° 20′ Ely.

If now it is found at any time that there is, say, 1° 45′ Easterly on East, it is evident that raising the C magnets $\frac{2}{10}$ inch will correct it, and careful observations on two adjacent cardinal points and an inter-cardinal point are enough to recompensate. This may ordinarily be done at no expense of time and with little trouble. More confidence may be felt in the result if observations for deviations are afterwards obtained on the four cardinal points and the mean of the results on opposite courses taken for the true value; this must be done if the variation is uncertain. A new set of data observations should be taken after a large change of magnetic latitude, but it will usually be found that the changes are slight.

Theoretically the quadrantal deviation, once corrected, should remain at zero. It will usually be found, however, that the position of the spheres must be changed with change of latitude. A convenient way of dealing with this is to construct a curve showing the positions of the spheres for varying values of H. A similar curve showing the position of the heeling magnet is also convenient.

Whenever the position of any corrector is changed, a note showing new position, date, latitude, longitude, H and θ should be made on one of the blank leaves of the compass record. A complete record of this kind will be found of the utmost value in keeping track of the compasses.

125. Correcting the Heeling Error.—The heeling error may be corrected by a method involving computation, together with certain observations on shore. A more practical method, however, is usually followed, though its results may be less precise. The heeling corrector is placed in its vertical tube, N. end uppermost in north latitudes, as this is almost invariably the required direction; the ship being on a course near North or South and rolling, observe the vibrations of the card, which, if the error is material, will be in excess of those due to the ship's real motion in azimuth; slowly raise or lower the corrector until the abnormal vibrations disappear, when the correction will be made for that latitude; but it must be readjusted upon any considerable change of geographical position.

In making this observation care must be taken to distinguish the vessel's "yawing" in a seaway from the apparent motion due to heeling error; for this reason it may be well to have an assistant to watch the ship's head and keep the adjuster informed of the real change in azimuth, by which means the latter may better judge the effect of the heeling error.

In the case of a sailing vessel, or one which for any reason maintains a nearly steady heel for a continuous period, the amount of the heeling error may be exactly ascertained by observing the azimuth of the sun, and corrected with greater accuracy than is possible with a vessel which is constantly rolling.

126. Flinders Bar.—The simplest method that presents itself for the placing of the Flinders bar is one which is available only for a vessel crossing the magnetic equator. Magnetic charts of the world show the geographical positions at which the dip becomes zero—that is, where a freely suspended needle is exactly horizontal and where there exists no vertical component of the earth's total magnetic force. In such localities it is evident that the factor of the semicircular deviation due to vertical induction disappears and that the whole of the existing semicircular deviation arises from subpermanent magnetism. If, then, when on the magnetic equator the compass be carefully compensated, the effect of the subpermanent magnetism will be exactly opposed by that of the semicircular correcting magnets. Later, as the ship departs from the magnetic equator, the semicircular deviation will gradually acquire a material value, which will be known to be due entirely to vertical induction, and if the Flinders bar be so placed as to correct it, the compensation of the compass will be general for all latitudes.

In following this method it may usually be assumed that the soft iron of the vessel is symmetrical with respect to the fore-and-aft line and that the Flinders bar may be placed directly forward of the compass or directly abaft it, disregarding the effect of components to starboard or port. It is therefore merely necessary to observe whether a vertical soft iron rod must be placed forward or abaft the compass to reduce the deviation, and, having ascertained this fact, to find by experiment the exact distance at which it completely corrects the deviation.

The Flinders bar frequently consists of a bundle of soft iron rods contained in a case, which is secured in a vertical position near the compass, its upper end level with the plane of the needles; in this method, the distance remaining fixed, the intensity of the force that it exerts is varied by increasing or decreasing the number of rods; this arrangement is more convenient and satisfactory than the employment of a single rod at a variable distance.

The United States Navy Flinders bar, Type II, is made of carefully annealed pure soft iron, 2 inches in diameter, total length 24 inches, consisting of pieces 12 inches, 6 inches, 3 inches, 1½ inches, and ¾ inch (2 of these) long. Hardwood blocks of the same dimensions are used to support the proper length of Flinders bar at the top of a fixed brass tube, which is secured ordinarily at the forward end of the binnacle in the fore-and-aft line.

It should be noted, however, that it is extremely difficult to get soft iron rods of a satisfactory quality, for, after being placed, they seldom fail to take up more or less subpermanent magnetism. This magnetism, due to shock of gunfire, vibration while cruising or on speed trials, etc., is subject to greater and more erratic changes than that of the harder portion of the hull, and its proximity to the compass intensifies the effect of the variations in its magnetic properties.

127. When it is not possible to correct the compass at the magnetic equator there is no ready practical method by which the Flinders bar may be placed; the operation will then depend entirely upon computation, and as a mathematical analysis of deviations is beyond the scope laid out for this work the details of procedure will not be gone into; the general principles involved are indicated, and students seeking more must consult the various works that treat the subject fully.

It has been explained that each coefficient of semicircular deviation (B and C) is made up of a subpermanent factor varying as $\frac{1}{H}$ and of a vertical induction factor varying as $\tan\theta$. If we indicate by the subscripts $_s$ and $_v$, respectively, the parts due to each force, we may write the equations of the coefficients:

$$B = B_s \times \frac{1}{H} + B_v \times \tan\theta; \text{ and}$$

$$C = C_s \times \frac{1}{H} + C_v \times \tan\theta.$$

Now if we distinguish by the subscripts $_1$ and $_2$ the values in the first and in the second position of observation, respectively, of those quantities that vary with the magnetic latitude, we have:

$$B_1 = B_s \times \frac{1}{H_1} + B_v \times \tan\theta_1,$$

$$B_2 = B_s \times \frac{1}{H_2} + B_v \times \tan\theta_2; \text{ and}$$

$$C_1 = C_s \times \frac{1}{H_1} + C_v \times \tan\theta_1,$$

$$C_2 = C_s \times \frac{1}{H_2} + C_v \times \tan\theta_2.$$

The values of the coefficients in both latitudes are found from the observations made for deviations; the values of the horizontal force and of the dip at each place are known from magnetic charts; hence we may solve the first pair of equations for B_s and B_v, and the second pair for C_s and C_v; and having found the values of these various coefficients, we may correct the effects of B_s and C_s by permanent magnets in the usual way and correct the remainder—that due to B_v and C_v—by the Flinders bar.

Strictly, the Flinders bar should be so placed that its repelling pole is at an angular distance from ahead equal to the "starboard angle" of the attracting pole of the vertical induced force, this angle depending upon the coefficients B_v and C_v; but since, as before stated, horizontal soft iron may usually be regarded as symmetrical, C_v is assumed as zero and the bar placed in the midship line.

128. To Correct Adjustment on Change of Latitude.—The compensation of quadrantal deviation, once properly made, remains effective in all latitudes, excepting as noted in article 110; but unless a Flinders bar is used a correction of the semicircular deviation made in one latitude will not remain accurate when the vessel has materially changed her position on the earth's surface. With this in mind the navigator must make frequent observations of the compass error during a passage and must expect that the table of residual deviations obtained in the magnetic latitude of compensation will undergo considerable change as that latitude is departed from. The new deviations may become so large that it will be found convenient to readjust the semicircular correcting magnets. This process is very simple.

When correctors at right angles are used, provide for steadying the ship, by an auxiliary compass or by the pelorus, upon two adjacent magnetic cardinal points (art. 122). Put the ship on heading North or South (magnetic), and raise or lower the athwartship magnets or alter their number until the deviation disappears; then steady on East or West (magnetic) and similarly adjust the fore-and-aft magnets. Swing ship for a new table of residual deviations.

129. It must be borne in mind that the compensation of the compass is not an exact science and that the only safeguard is unceasing watchfulness on the navigator's part. As the ship's iron is partly "hard" and partly "soft," the subpermanent magnetism may change appreciably from day to day, especially in a new ship as the magnetism absorbed in building "shakes out." After a ship has been in service for one or two years, the magnetic conditions may be said to be "settled." They undergo changes, however, to a greater or less extent, on account of the following influences or conditions:

(*a*) Continuous steaming on one general course for several days, especially in rough weather, or lying alongside a dock on one heading for a long period.

(*b*) Shock of gunfire, even on a ship that has been in commission for more than a year, has been known to introduce an 8° error, which disappeared in the course of a few days.

(*c*) Extensive alterations or repairs in the vicinity of the compass. The use of scaling hammers on a military top caused a 3° change in one of the U. S. S. *Connecticut's* compasses.

(*d*) Steaming with boilers (especially under forced draft) whose funnel is near the compass has been known to cause a change of more than 10°, the retained magnetism being "cooked out."

(*e*) On the U. S. S. *Oregon*, a grounded searchlight circuit caused a change of 9°.

(*f*) Ships have reported changes of as much as 7° when struck by lightning or after passing through very severe thunderstorms.

The binnacle fittings must be carefully inspected from time to time, to see that the correctors have not changed position. At least once a year the quadrantal correctors should be examined for polarity. This can be done by moving them, one at a time, as close to the compass as practicable and then revolving them slowly about the vertical axis; if the compass is deflected, the magnetism should be removed by bringing the sphere to a low red heat and then letting it cool slowly.

There is no excuse for large deviations in a standard or steering compass, and they should not be allowed to exist.

CHAPTER IV.

PILOTING.

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130. *Piloting*, in the sense given the word by modern and popular usage, is the art of conducting a vessel in channels and harbors and along coasts, where landmarks and aids to navigation are available for fixing the position, and where the depth of water and dangers to navigation are such as to require a constant watch to be kept upon the vessel's course and frequent changes to be made therein.

Piloting is the most important part of navigation and the part requiring the most experience and nicest judgment. An error in position on the high seas may be rectified by later observation, but an error in position while piloting usually results in disaster. Therefore the navigator should make every effort to be proficient in this important branch, bearing in mind that a modern vessel is usually safe on the high seas and in danger when approaching the land and making the harbor.

131. *Requisites.*—The navigator should have ready on approaching the land the charts of the coast and the largest scale detail charts of the locality at which he expects to make his landfall, the sailing directions, and the light and buoy list, all corrected for the latest information from the Notices to Mariners and other sources. The usual instruments employed in navigation should be at hand and in good working order. The most important instrument—the sounding machine—should be in place and in order at least a day before the land is to be made. *The importance of the sounding machine can not be exaggerated.* The latest deviation table for the standard compass must be at hand.

132. Laying the Course.—Mark a point upon the chart at the ship's position; then mark another point for which it is desired to steer; join the two by a line drawn with the parallel ruler, and, maintaining the direction of the line, move the ruler until its edge passes through the center of the compass rose and note the direction. If the compass rose indicates *true* directions, this will be the true course; and must be corrected for variation and deviation (by applying each in the *opposite* direction to its name) to obtain the compass course; if it is a *magnetic* rose, the course need be corrected for deviation only.

Before putting the ship on any course a careful look should be taken along the line over which it leads to be assured that it clears all dangers.

133. Methods of Fixing Position.—A navigator in sight of objects whose positions are shown upon the chart may locate his vessel by any one of the following methods: (*a*) cross bearings of two known objects; (*b*) the bearing and distance of a known object; (*c*) the bearing of a known object and the angle between two known objects; (*d*) two bearings of a known object separated by an interval of time, with the run during that interval; (*e*) sextant angles between three known objects. Besides the foregoing there are two methods by which, without obtaining the precise position, the navigator may assure himself that he is clear of any particular danger. These are: (*f*) the danger angle; (*g*) the danger bearing.

The choice of the method will be governed by circumstances, depending upon which is best adapted to prevailing conditions.

134. Cross Bearings of Two Known Objects.—Choose two objects whose position on the chart can be unmistakably identified and whose respective bearings from the ship differ, as nearly as possible by 90°; observe the bearing of each, either by compass or pelorus, taking one as quickly as possible after the other; see that the ship is on an even keel at the time the observation is made, and, if using the pelorus, be sure also that she heads exactly on the course for which the pelorus is set. Correct the bearings so that they will be either true or magnetic, according as they are to be plotted by the true or magnetic compass rose of the chart—that is, if observed by compass, apply deviation and variation to obtain the true bearing, or deviation only to obtain the magnetic; if observed by pelorus, that instrument should be set for the true or magnetic heading, according as one or the other sort of reading is required, and no further correction will be necessary. Draw on the chart, by means of the parallel rulers, lines which shall pass through the respective objects in the direction that each was observed to bear. As the ship's position on the chart is known to be at some point of each of these lines, it must be at their intersection, the only point that fulfills both conditions.

In figure 13, if A and B are the objects and OA and OB the lines passing through them in the observed directions, the ship's position will be at O, their intersection.

The plotting of a position from two bearings is greatly facilitated by the use of a plotter devised by Lieut. R. A. Koch, United States Navy, as reference to the compass rose on the chart, the use of parallel rulers, and the drawing of lines on the chart are obviated. A brief description of this plotter and its uses is as follows: All materials except bolt and washers are transparent. A square (7 by 7 inches) ruled with two series of lines at right angles about one-half inch apart, and a disk (7½ inches in diameter) marked in degrees are placed on a central hollow bolt of brass and are capable of being clamped together with any degree of friction required. Three arms are placed so as to revolve around the same hollow bolt and can be clamped together in any position. In order to plot a position from compass bearings of two objects, the zero mark of the disk should be revolved to the East or West of the true North and South line of the square by an amount equal to the compass error in degrees. Two of the arms are then set by the degrees on the disk to the two observed compass bearings. The plotter is then manipulated on the chart until the two arms intersect the objects observed and the vertical lines on the square are parallel to the meridians of the chart. Mark the point of intersection of the arms by inserting a pencil in the hollow central bolt. An arm may then be swung to intersect any object on the chart and the compass bearing to that object read from the disk. The new course toward any destination whose bearing is thus read off may be found with closeness by applying to the bearing the difference between the deviation of the compass on the heading on which the bearings were taken and the deviation on the heading in the indicated direction of the destination. This plotter can also be used to obtain the error of the compass from bearings of three objects by compass.

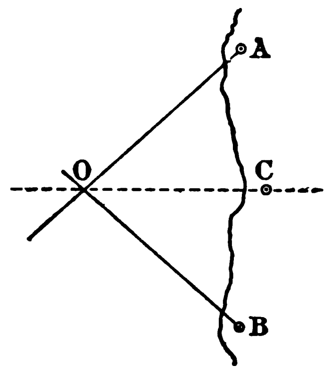

FIG. 13.

135. If it be possible to avoid it, objects should not be selected for cross bearings which subtend an angle at the ship of less than 30° or more than 150°, as, when the lines of bearing approach parallelism, a small error in an observed bearing gives a large error in the result. For a similar reason objects near the ship should be taken in preference to those at a distance.

136. When a third object is available a bearing of that may be taken and plotted. If this line intersects at the same point as the other two (as the bearing OC of the object C in the figure), the navigator may have a reasonable assurance that his "fix" is correct; if it does not, it indicates an error somewhere, and it may have arisen from inaccurate observation, incorrect determination or application of the deviation, or a fault in the chart.

137. What may be considered as a form of this method can be used when only one known object is in sight by taking, at the same instant as the bearing, an altitude of the sun or other heavenly body and noting the time; work out the sight and obtain the Sumner line (as explained in Chapter XV), and the intersection of this with the direction line from the object will give the observer's position in the same way as from two terrestrial bearings.

138. Bearing and Distance of a Known Object.—When only one object is available, the ship's position may be found by observing its bearing and distance. Follow the preceding method in the manner of taking, correcting, and plotting the bearing; then, on this line, lay off the distance from the object, which will give the point occupied by the observer. In figure 14, if A represents the object and AO the bearing and distance, the position sought will be at O.

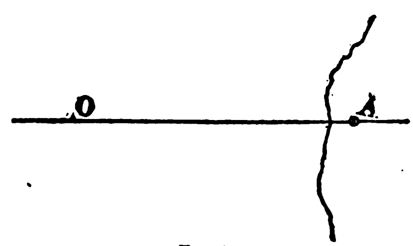

FIG. 14.

The stadimeter is an instrument, similar to a sextant, employed in the United States Navy, reading directly the distance of the object observed when set for the height of the object.

Range-finding instruments are used in the United States Navy for readily finding the distance of an observed object, and these instruments do not require knowledge of the height of the object. These instruments are accurate for navigational purposes up to ten thousand yards.

139. It is not ordinarily easy to find directly the distance of an object at sea. The most accurate method is when its height is known and it subtends a fair-sized angle from the ship, in which case the angle may be measured by a sextant[a] and the distance computed or taken from a table. Table 33 of this work gives distances up to 5 miles, corresponding to various heights and angles. Captain Lecky's "Danger Angle and Offshore Distance Tables" carries the computation much further. The use of this method at great distances must not be too closely relied upon, as small errors, such as those due to refraction, may throw out the results to a material extent, but it affords an excellent approximation; and, as this method of fixing position is employed only when no other is available, the best possible approximation has to suffice.

In measuring vertical angles, strictness requires that the observation should be so made that the angle at the foot of the object should equal 90° and that the triangle be a right triangle, as CMN, figure 15, where the line OM is truly horizontal, and not as in the triangle O′MN, where the condition is not fulfilled. This error is inappreciable, however, save at very close distances, when it may be sufficiently corrected by getting down as low as possible on board the vessel, so that the eye is near the water line. One condition exists, however, where the error is material—that shown in

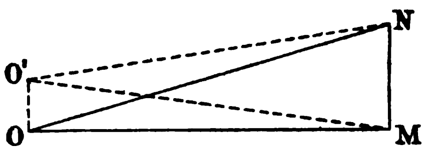

Fig. 15.

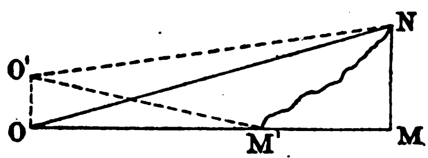

Fig. 16.

figure 16, where the visible shore line is at M′, a considerable distance from M, the point vertically below the summit. In this case there is nothing to mark M in the observer's eye, and it is essential that all angles be measured from a point close down to the water line.

If a choice of objects can be made, the best results will be obtained by observing that one which subtends the greatest angle, as small errors will then have the least effect.

140. There is another method, known as Buckner's method, for determining the distance of an object, which is available under certain circumstances. This consists in observing, from a position aloft, the angle between the object and the line of the sea horizon beyond. By reference to Table 34 will be found the distance in yards corresponding to different angles for various heights of the observer from 20 to 120 feet. The method is not accurate beyond moderate distances (the table being limited to 5,000 yards) and is obviously only available for finding the distance of an isolated object, such as an islet, vessel, or target, over which the horizon may be seen. In employing this method the higher the position occupied by the observer the more precise will be the results.

141. In observing small angles, such as those that occur in the methods just described, it is sometimes convenient to measure them *on and off* the limb of the sextant. First look at the bottom of the object and reflect the top down into coincidence; then look through the transparent part of the horizon glass at the top and bring the bottom up by its reflected ray. The mean of the two readings will be the true angle, the index correction having been eliminated by the operation.

142. When the methods of finding distance by a vertical or a horizon angle are not available, it must be obtained by such means as exist. Estimate the distance by the appearance; take a sounding, and note where the depth falls upon the line

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[a] The use of the sextant is explained in Chapter VIII.

of bearing; at night, if atmospheric conditions are normal, consider that the distance of a light when sighted is equal to its maximum range of visibility, remembering that its range is stated for a height of eye of 15 feet; or employ such method as suggests itself under the circumstances, regarding the result, however, as an approximation only.

143. The Bearing of a Known Object and the Angle between Two Known Objects.—This method is seldom employed, as the conditions always permit of cross bearings being taken, and the latter is generally considered preferable.

Take a bearing of a known object by compass or pelorus and observe the sextant angle between some two known objects. The line of bearing is plotted as in former methods. In case one of the objects of the observed angle is that whose bearing is taken, the angle is applied, right or left as the case may be, to the bearing; thus giving the direction of the second object, which is plotted from the compass rose and parallel rulers. If the object whose bearing is taken is not one of the objects of the angle, lay off the angle on a three-armed protractor, or piece of tracing paper, and swing it (keeping the legs or lines always over the two objects) until it passes over the line of bearing, which defines the position of the ship; there will, except in special cases, be two points of intersection of the line with the circle thus described, and the navigator must know his position with sufficient closeness to judge which is correct.

144. Two Bearings of a Known Object.—This is a most useful method, which is frequently employed, certain special cases arising thereunder being particularly easy of application. The process is to take a careful bearing and at the same moment read the patent log; then, after running a convenient distance, take a second bearing and again read the log, the difference in readings giving the intervening run; when running at a known speed, the time interval will also afford a means for determining the distance run.

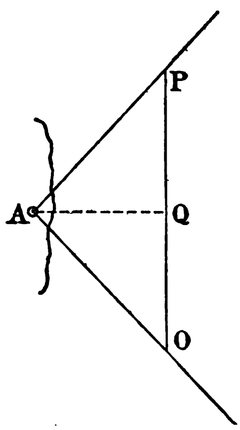

Fig. 17.

The problem is as follows: In figure 17, given OA, the direction of a known object, A, at the first observation; PA, the direction at the second observation; and OP, the distance traversed between the two; to find AP, the distance at the second observation.

Knowing the angle POA, the angular distance of the object from right ahead at the first bearing; OPA, the angular distance from right astern at the second bearing; and OP, the distance run; we have by Plane Trigonometry:

$$PAO = 180° - (POA + OPA); \text{ and}$$
$$AP = OP \times \frac{\sin POA}{\sin PAO}.$$

If, as is frequently the case, we desire to know the distance of passing abeam, we have:

$$AQ = AP \times \sin OPA.$$

Tables 5A and 5B give solutions for this problem, the former for intervals of bearing of quarter points, the latter for intervals of two degrees. The first column of each of these tables gives the value of AP, the distance of the ship from the observed object at the time of taking the last bearing, for values of OP equal to unity; that is, for a run between bearings of 1 mile. The second column gives AQ, the distance of the object when it bears abeam, likewise for a value of OP of 1 mile. When the run between bearings is other than 1 mile, the number taken from the table must be used as a multiplier of that run to give the required distance.

Example: A vessel steering north takes a bearing of a light NW. ½ W.; then runs 4.3 miles, when the bearing is found to be WSW. Required the distance of the light at the time of the second bearing.

Difference between course and first bearing, 4½ pts.
Difference between course and second bearing, 10 pts.
Multiplier from first column, Table 5A, 0.88.
4.3 miles × 0.88 = 3.8 miles, distance at second bearing.

EXAMPLE: A vessel on a course 128° takes the first bearing of an object at 154°, and the second at 182°, running in the interval 0.8 mile. Required the distance at which she will pass abeam.

Difference between course and first bearing, 26°
Difference between course and second bearing, 54°.
Multiplier from second column, Table 5B, 0.76.
0. 8 mile × 0.76 = 0. 6 mile, distance of passing abeam.

145. As has been said, there are certain special cases of this problem where it is exceptionally easy of application; these arise when the multiplier is equal to unity and the distance run is therefore equal to the distance from the object. When the angular distance on the bow at the second bearing is twice as great as it was at the first bearing, the distance of the object from the ship *at second bearing* is equal to the run, the multiplier being 1.0. For if, in figure 18, when the ship is in the first position, O, the object A bears $\alpha°$ on the bow, and at the second position, P, $2\alpha°$, we have in the triangle APO, observing that $APO = 180° - 2\alpha$, and $POA = \alpha$:

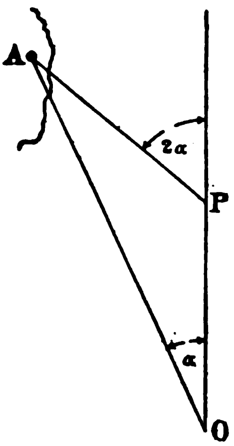

Fig. 18.

$$\begin{aligned} PAO &= 180° - (POA + APO), \\ &= 180° - (\alpha + 180° - 2\alpha), \\ &= \alpha. \end{aligned}$$

Or, since the angles at O and A are equal to each other, the sides OP and AP are equal or the distance at second bearing is equal to the run. This is known as *doubling the angle on the bow.*

146. A case where this holds good is familiar to every navigator as the *bow and beam bearing,* where the first bearing is taken when the object is broad on the bow (four points or 45° from ahead) and the second when it is abeam (eight points or 90° from ahead); in that case the distance at second bearing and the distance abeam are identical and equal to the run between bearings.

147. When the first bearing is 26½° from ahead, and the second 45°, the distance *at which the object will be passed abeam* will equal the run between bearings. This is true of any two such bearings whose natural cotangents differ by unity, and the following table is a collection of solutions of this relation in which the pairs of bearings are such that, when observed in succession from ahead upon the same fixed object, the distance run between the bearings will be equal to the distance of the fixed object when it bears abeam, provided that a steady course has been steered, unaffected by current or drift.

The marked pairs will probably be found the most convenient ones to use, as they involve whole degrees only.

Bearings from ahead.

First.	Second.	First.	Second.	First.	Second.
°	°	°	°	°	°
20	29¾	28	48½	37	71¾
21	31¾	*29	51	38	74¼
*22	34	30	53¾	39	76¾
23	36¼	31	56¼	*40	79
24	38¾	*32	59	41	81¼
*25	41	33	61½	42	83½
26	43½	34	64¼	43	85¾
26½	45	35	66¾	*44	88
*27	46	36	69¼	*45	90

When the fixed object bears as per any entry of the first column, take the time and the reading of the patent log. Repeat this procedure on reaching the bearing of the adjacent entry in the second column. The difference of the patent-log readings will be the distance at which the fixed object will be passed abeam.

This general solution includes the 26½°–45° rule as well as the seven-tenths rule to be explained later; furthermore, it has the advantage that the approximate determination of the distance offshore, at which the fixed object will be passed, need not wait for the 45° bearing. There are two whole-degree pairs by which such a determination can be made before the 45° bearing is reached. It is possible to get five whole-degree bearings or observations by the time the fixed object bears 30° forward of the beam, as follows: 22°–34°, 25°–41°, 27°–46°, 29°–51°, 32°–59°. Of these, the last three should be reasonably accurate; the acuteness of the first angle in all such observations accounts for the discrepancies noted in practice. The use of the table given above may be found to be more convenient than the methods of plotting about to be described, and the use of tables 5A and 5B; but it does not take the place of those methods. Tables 5A and 5B cover all combinations of bearings in which the first bearing is taken when the object is 20° or more on the bow.

The Seven-tenths Rule.—If bearings of the fixed object be taken at two (2) and four (4) points on the bow (22½° and 45°), seven-tenths (0.7) of the run between bearings will be the distance at which the point will be passed abeam.

From the combination of the seven-tenths rule and the 26½°–45° rule, there follows an interesting corollary, i. e., if bearings of an object at 22½° and 26½° on the bow be taken, then seven-thirds (7/3) of the distance run in the interval will be the distance when abeam.

If a bearing is taken when an object is two points (22½°) forward of the beam and the run until it bears abeam is measured, then its distance when abeam is seven-thirds (7/3) of the run. This rule, particularly, is only approximate.

In case the 45° bearing on the bow is lost, in order to find the distance abeam that the object is passed, note the time when the object bears 26½° forward of the beam, and again when it has the same bearing abaft the beam; the distance run in this interval is the distance of the object when it was abeam.

To steer an arc course in order to round a light, point, or other object without fixes and be sure the course itself does not decrease the initial distance: Provided there is no current, stand on course until the light is at the required distance, determined by one or more of the methods described. Immediately bring the light abeam, and do not let it get forward of the beam again, then the course will not decrease the initial distance. When the light is one-half point abaft the beam again bring it abeam; hold course until it is again one-half point abaft the beam, repeating this procedure until the light is rounded. A polygon is thus described, whose nearest approach to the light is the initial distance. The number of sides of the polygon may be increased indefinitely, so that the light may be rounded, by changing the course just enough to keep the light abeam, after it is first brought abeam.

148. There is a *graphic method* of solving this problem that is considered by some more convenient than the use of multipliers. Draw upon the chart the lines OA and PA (fig. 19), passing through the object on the two observed bearings; set the dividers to the distance run, OP; lay down the parallel rulers in a direction parallel to the course and move them toward or away from the observed object until some point is found where the distance between the lines of bearing is exactly equal to the distance between the points of the dividers; in the figure this occurs when the rulers lie along the line OP, and therefore O represents the position of the ship at the first bearing and P at the second. For any other positions O′P′, O″P″, the condition is not fulfilled.

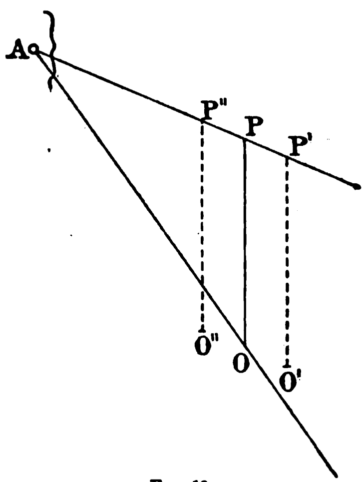

Fig. 19.

149. Another graphic solution is given by the Mooring and Maneuvering Board and the various modifications of it that are in use among navigators.

150. The method of obtaining position by two bearings of the same object is one of great value, by reason of the fact that it is frequently necessary to locate the ship when there is but one landmark in sight. Careful navigators seldom, if ever, miss the opportunity for a bow and beam bearing in passing a lighthouse or other well-plotted object; it involves little or no trouble, and always gives a feeling of added security, however little the position may be in doubt. If about to pass an object abreast of which there is a danger—a familiar example of which is when a lighthouse marks a point off which are rocks or shoals—a good assurance of clearance should be obtained before bringing it abeam, either by doubling the angle on the bow, or, if the object be sighted in time, by using any of the pairs of bearings tabulated under article 147.

151. It must be remembered that, however convenient, the fix obtained by two bearings of the same object will be in error unless the course and distance are correctly estimated, the course "made good" and the distance "over the ground" being required. Difficulty will occur in estimating the exact course when there is bad steering, a cross current, or when a ship is making leeway; errors in the allowed run will arise when she is being set ahead or back by a current or when the logging is inaccurate. A current directly with the course of the ship, if unallowed for, will give a determination of position too close to the object observed; and a current directly against the course of the ship, if unallowed for, will give a determination of position too far away from the object observed. The existence of such a current *will not be* revealed by taking more than two successive bearings. All such observations will place the ship on the same apparent course, which course will be parallel to the course made good and to the course steered but in error in its distance from the observed object by an amount dependent upon the ratio of the speed of ship over ground to the speed of ship by log. A current oblique to the course of the ship will give a determination of position which will be erroneous. The existence of such a current but not its amount *will be* revealed by taking more than two observations; in this case, following the usual method of plotting, the determination resulting from any two successive bearings will fail to agree with the determination from any other two. If, in such a case, the observed bearings be drawn upon the chart and the distances run by log between them be laid down on the scale of the chart upon a piece of paper, a course may be found by trial, upon which course the intervals of run correspond with the intervals between the lines of bearing. The apparent course thus determined, which must always be oblique to the course steered, will be parallel to the course actually being made good, but will be in error in its distance from the observed object by an amount dependent upon the ratio of the speed of ship over the ground to the speed of ship by log. If there is an apparant shortening of the distance run from earlier to later observations, or a shortening of the time if the speed is invariable, there is a component of set toward the fixed object. Therefore, if in a current of any sort, due allowance must be made, and it should be remembered that more dependence can be placed upon a position fixed by simultaneous bearings or angles, when two or more objects are available, than by two bearings of a single object.

152. Sextant Angles between Three Known Objects.—This method, involving the solution of the *three-point problem*, will, if the objects be well chosen, give the most accurate results of any. It is largely employed in surveying, because of its precision; and it is especially valuable in navigation, because it is not subject to errors arising from imperfect knowledge of the compass error, improper logging, or the effects of current, as are the methods previously described.

Three objects represented on the chart are selected and the angles measured with sextants of known index error between the center one and each of the others. Preferably there should be two observers and the two angles be taken simultaneously, but one observer may first take the angle which is changing more slowly, then take the other, then repeat the first angle, and consider the mean of the first and last observations as the value of the first angle. The position is usually plotted by means of the three-armed protractor, or station-pointer (see art. 428, Chap. XVII). Set the right and left angles on the instrument, and then move it over the chart until the three beveled edges pass respectively and simultaneously through the three objects. The center of the instrument will then mark the ship's position, which may be pricked on the chart or marked with a pencil point through the center hole. When the three-armed protractor is not at hand, the tracing-paper protractor will prove an excellent substitute, and may in some cases be preferable to it, as, for instance, when the objects angled on are so near the observer as to be hidden by the circle of the instrument. A graduated circle printed upon tracing paper permits the angles being readily laid off, but a plain piece of tracing paper may be used and the angles marked by means of a small protractor. The tracing-paper protractor permits the laying down, for simultaneous trial, of a number of angles, where special accuracy is sought.

153. The three-point problem, by which results are obtained in this method, is: To find a point such that three lines drawn from this point to three given points shall make given angles with each other.

Let A, B, and C, in figure 20, be three fixed objects on shore, and from the ship, at D, suppose the angles CDB and ADB are found equal, respectively, to 40° and 60°.

With the complement of CDB, 50°, draw the lines BE and CE; the point of intersection will be the center of a circle, on some point of whose circumference the ship must be. Then, with the complement of the angle ADB, 30°, draw the lines AF and BF, meeting at F, which point will be the center of another circle, on some point of whose circumference the ship must be. Then D, the point of intersection of the circumference of the two circles, will be the position of the ship.

The correctness of this solution may be seen as follows: Take the first circle, DBC; in the triangle EBC, the angle at E, the center, equals $180° - 2 \times 50° = 2\ (90° - 50°)$, twice the complement of 50°, which is twice the observed angle; now if the angle at the center subtended by the chord BC equals twice the observed angle, then the angle at any point on the circumference subtended by that chord, which equals half the angle at the center, equals the observed angle; so the required condition is fulfilled. Should either of the angles exceed 90°, the excess of the angle over 90° must be laid off on the opposite side of the lines joining the stations.

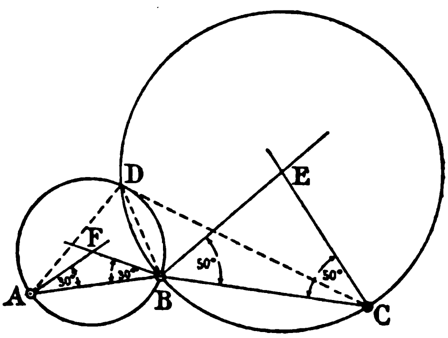

Fig. 20.

It may be seen that the intersection of the circles becomes less sharp as the centers E and F approach each other; and finally that the problem becomes indeterminate when the centers coincide, that is, when the three observed points and the observer's position all fall upon the same circle; the two circles are then identical and there is no intersection; such a case is called a "revolver," because the protractor will revolve around the whole circle, everywhere passing through the observed points. The avoidance of the revolver and the employment of large angles and short distances form the keys to the selection of favorable objects.

Generally speaking, the observer, in judging which objects are the best to be taken, can picture in his eye the circle passing through the three points and note whether it comes near to his own position. If it does, he must reject one or more of the objects for another or others. It should be remembered that he must avoid not only the condition where the circle passes exactly through his position (when the problem is wholly indeterminate), but also all conditions approximating thereto, for in such cases the circles will intersect at a very acute angle, and the inevitable small errors of the observation and plotting will produce large errors in the resulting fix.

Without giving an analysis of reasons, which may be found in various works that treat the problem in detail, the following may be enumerated as the general conditions which result in a *good* fix:

(*a*) When the center object of the three lies between the observer and a line joining the other two, or lies nearer than either of the other two.

(*b*) When the sum of the right and left angles is equal to or greater than 180°.

(*c*) When two of the objects are in range, or nearly so, and the angle to the third is not less than 30°.

(*d*) When the three objects are in the same straight line.

A condition that limits all of these is that angles should be large—at least as large as 30°—excepting in the case where two objects are in range or nearly so, and then the other angle must be of good size. When possible, near objects should be used rather than distant ones. The navigator should not fall into the error of assuming that objects which would give good cuts for a cross bearing are necessarily favorable for the three-point solution.

In a revolver, the angle formed by lines drawn from the center object to the other two, added to the sum of the two observed angles, equals 180°. A knowledge of this fact may aid in the choice of objects.

If in doubt as to the accuracy with which the angles will plot, a third angle to a fourth object may be taken. Another way to make sure of a doubtful fix is to take one compass bearing, by means of which even a revolver may be made to give a good position.

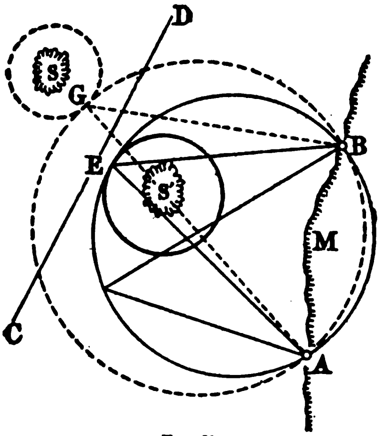

Fig. 21.

154. The Danger Angle.—When sailing along a coast, to avoid sunken rocks, or shoals, or dangerous obstructions at or below the surface of the water, and which are marked on the chart, the navigator may pass these at any desired distance by using what is known as a *danger angle*, of which there are two kinds, namely, the horizontal and vertical danger angles; the former requires two well-marked objects indicated on the chart, lying in the direction of the coast, and sufficiently distant from each other to give a fair-sized horizontal angle; the latter requires a well-charted object of known height.

155. In figure 21, let AMB be a portion of the coast along which a vessel is sailing on the course CD; A and B two prominent objects shown on the chart; S and S′ are two outlying shoals, reefs, or dangers. In order to pass outside of the danger S′ take the middle point of the danger as a center and the given distance from the center it is desired to pass as radius, and describe a circle. Pass a circle through A and B tangent to the seaward side of the first circle. To do this, it is only necessary to join A and B and draw a line perpendicular to the middle of AB; and then ascertain by trial the location of the center of the circle EAB. Measure the angle AEB, set the sextant to this angle, and remembering that AB subtends the same angle at all points of the arc AEB, the ship will be outside the arc AEB, and clear the danger S′, as long as AB does not subtend an angle greater than AEB, to which the sextant is set. At the same time in order to avoid the danger S, take the middle point of the danger S and with the desired distance as a radius describe a circle. Pass a second circle through A and B tangent to this circle at G, measure the angle AGB with a protractor, then, as long as the chord AB subtends an angle greater than AGB, the ship will be inside the circle AGB. Therefore, the ship will pass between the dangers S and S′ as long as the angle subtended by AB is less than AEB and greater than AGB.

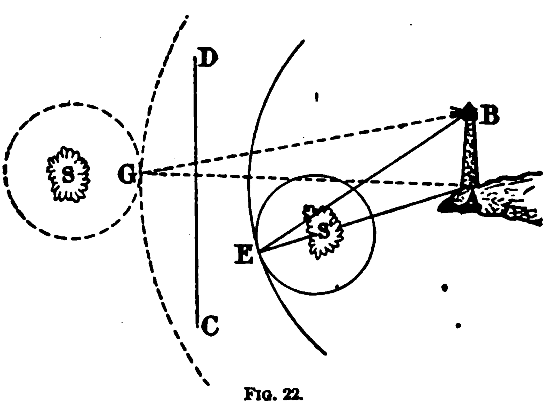

Fig. 22.

156. The vertical danger angle involves the same general principle, as can be readily seen without explanation by reference to the figure 22 in which AB represents a vertical object of known height.

157. The Danger Bearing.—This is a method by which the navigator is warned by a compass bearing when the course is leading into danger. Suppose a vessel to be steering a course, as indicated in figure 23, along a coast which must not be approached within a certain distance, the landmark A being a guide. Let the navigator draw through A the line XA, clear of the danger at all points, and note its direction by the compass rose; then let frequent bearings be taken as the ship proceeds, and so long as the bearings, YA, ZA, are to the *right* of XA he may be assured that he is on the *left* or safe side of the line.

If, as in the case given, there is but one object in sight and that nearly ahead, it would be very difficult to get an exact position, but this method would always show whether or not the ship was on a good course, and would, in consequence, be of the greatest value. And even if there were other objects visible by which to get an accurate fix it would be a more simple matter to note, by an occasional glance over the sightvane of the pelorus or compass, that the ship was making good a safe course than to be put to the necessity of plotting the position each time.

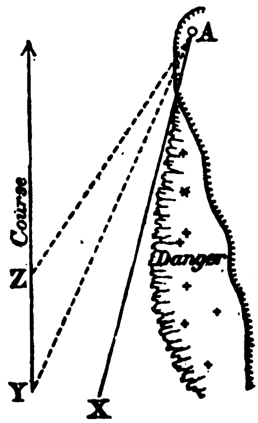

FIG. 23.

158. It will occasionally occur that two natural objects will so lie that when in range they mark a danger bearing; advantage should be taken of all such, as they are easier to observe than a compass bearing; but if in a locality with which the navigator has not had previous acquaintance the compass bearing of all ranges should be observed and compared with that indicated on the chart in order to make sure of the identity of the objects. The utility of ranges, either artificial or natural, as guides in navigation, extends also to established lines of bearing giving the true or magnetic direction of fixed objects, such as lines of bearing limiting the sectors of navigational lights.

159. SOUNDINGS.—The practice should be followed of employing one or two leadsmen to take and report soundings continuously while in shoal water or in the vicinity of dangers. The soundings must not be regarded as fixing a position, but they afford a check upon the positions obtained by other methods. An exact agreement with the soundings on the chart need not be expected, as there may be some little inaccuracies in reporting the depth on a ship moving with speed through the water, or the tide may cause a discrepancy, or the chart itself may lack perfection; but the soundings should agree in a general way, and a marked departure from the characteristic bottom shown on the chart should lead the navigator to verify his position and proceed with caution; especially is this true if the water is more shoal than expected.

160. But if the soundings in shallow water when landmarks are in sight serve merely as an auxiliary guide, those taken (usually with the patent sounding machine or deep-sea lead) when there exist no other means of locating the position, fulfill a much more important purpose. In thick weather, when approaching or running close to the land, and at all times when the vessel is in less than 100 fathoms of water and her position is in doubt, soundings should be taken continuously and at regular intervals, and, with the character of the bottom, systematically recorded. By laying the soundings on tracing paper, along a line which represents the track of the ship according to the scale of the chart, and then moving the paper over the chart, keeping the various courses parallel to the corresponding directions on the chart, until the observed soundings agree with those laid down, the ship's position will in general be quite well determined. While some localities, by the sharpness of the characteristics of their soundings, lend themselves better than others to accurate determinations by this method, there are few places where the mariner can not at least keep out of danger by the indications, even if they tell him no more than that the time has come when he must anchor or lie off till conditions are more favorable.

161. LIGHTS.—Before coming within range of a light the navigator should acquaint himself with its characteristics, so that when sighted it will be recognized. The charts, sailing directions, and light lists give information as to the color, character, and range of visibility of the various lights. Care should be taken to note all of these and compare them when the light is seen. If the light is of the flashing, revolving, or intermittent variety the duration of its periods should be noted to identify it. If a fixed light, a method that may be employed to make sure that it is not a vessel's light is to descend several feet immediately after sighting it and observe if it disappears from view; a navigational light will usually do so, excepting in misty weather, while a vessel's light will not. The reason for this is that navigational lights are as a rule sufficiently powerful to be seen at the farthest point to which the ray can reach without being interrupted by the earth's curvature. They are therefore seen at the first moment that the ray reaches an observer on a ship's deck, and are cut off if he lowers the eye. A vessel's light, on the other hand, is usually limited by its intensity and does not carry beyond a distance within which it is visible at all heights.

Care must be taken to avoid being deceived on first sighting a light, as there are various errors into which the inexperienced may fall. The glare of a powerful light is often seen beyond the distance of visibility of its direct rays by the reflection downward from particles of mist in the air; the same mist may also cause a white light to have a distinctly reddish tinge, or it may obscure a light except within short distances. When a light is picked up at the extreme limit at which the height of the observer will permit, a fixed light may appear flashing, as it is seen when the ship is on the crest of a wave, and lost when in the hollow.

Many lights are made to show different colors in different sectors within their range, and by consulting his chart or books, the navigator may be guided by the color of the sector in which he finds himself; in such lights one color is generally used on bearings whence the approach is clear, and another covers areas where dangers are to be encountered.

The visibility of lights is usually stated for an assumed height of the observer's eye of 15 feet, and must be modified accordingly for any other height. But it should be remembered that atmospheric and other conditions considerably affect the visibility, and it must not be positively assumed, on sighting a light, even in perfectly clear weather, that a vessel's distance is equal to the range of visibility; it may be either greater or less, as the path of a ray of light near the horizon receives extraordinary deflection under certain circumstances; the conditions governing this deflection are discussed in article 296, Chapter X.

162. Buoys.—While buoys are valuable aids, the mariner should always employ a certain amount of caution in being guided by them. In the nature of things it is never possible to be certain of finding buoys in correct position, or, indeed, of finding them at all. Heavy seas, strong currents, ice, or collisions with passing vessels may drag them from their places or cause them to disappear entirely, and they are especially uncertain in unfrequented waters, or those of nations that do not keep a good lookout upon their aids to navigation. When, therefore, a buoy marks a place where a ship must be navigated with caution, it is well to have a danger angle or bearing as an additional guide instead of placing too much dependence upon the buoy being in place.

Different nations adopt different systems of coloring for their buoys; an important feature of many such systems, including those adopted by the United States and various other great maritime nations (though not all), consists in placing red buoys to be left on the starboard hand of a vessel entering a harbor or fairway, and black buoys on the port hand. In these various systems the color and character of the buoys are such as to denote the special purpose for which they are employed.

163. Fogs and Fog Signals.—As with lights, the navigator should, in a fog, acquaint himself with the characteristics of the various sound signals which he is likely to pick up, and when one is heard, its periods should be timed and compared with those given in the light lists to insure its proper identity.

Experiment has demonstrated that sound is conveyed through the atmosphere in a very uncertain way; that its intensity is not always increased as its origin is approached, and that areas within its range at one time, will seem silent at another. Add to these facts the possibility that, for some cause, the signal may not be working as it should be, and we have reason for observing the rule to proceed with the utmost caution when running near the land in a fog.

Although the transmission of sound through water from the submarine bells that have been installed on many light vessels and at points of danger is much more certain than the transmission of sound through air and can be received in such a way by vessels equipped with submerged microphones on each side as to enable the direction of the submarine bell to be approximately determined, yet the lead continues to prove an ever-serviceable guide, and should accordingly be in constant use.

The method of plotting soundings described in article 160 will give the most reliable position that is obtainable. Moreover, the lead will warn the navigator of the approach to shallow water, when, if his position is at all in doubt, it is wisest to to anchor before it becomes too late.

When running slowly in a fog (which caution, as well as the law, requires that one should do) it must be borne in mind that the relative effect of current is increased; for instance, the angle of deflection from the course caused by a cross-set is greater at low than at high speed.

It is worth remembering that when in the vicinity of a bold bluff shore vessels are sometimes warned of a too close approach by having their own fog signals echoed back from the cliffs; indeed, from a knowledge of the velocity of sound (art. 314, Chap. XI) it is possible to gain some rough idea of the distance in such a case.

When radio-stations, equipped with fog-signaling apparatus, send out simultaneous radio and sound signals, distances from the sending station can be found by noting the elapsed interval between the time of arrival of radio signal and sound signal, and multiplying this interval expressed in seconds by the velocity per second of sound in air, or the velocity per second of sound in water, according as the sound signals are received through air or through water.

By thus determining the distance from a fog-signal station to different positions between which the course and distance are known, the position of the vessel could be approximately found in a manner analogous to that which would apply in figure 18 if the distances AO and AP were known in addition to the length and direction of OP.

164. Tides and Currents.—The information relating to the tides given on the chart and in other publications should be studied, as it is of importance for the navigator to know not only the height of the tide above the plane of reference of the chart, but also the direction and force of the tidal current.

The plane of reference adopted for soundings varies with different charts; on a large number it is that of mean low water, and as no plane of reference above that of mean low water is ever employed the navigator may with safety refer his soundings to that level when in doubt.

When traversing waters in which the depth exceeds the vessel's draft by but a small margin, account must be taken of the fact that strong winds or a high barometer may cause the water to fall below even a very low plane of reference. On coasts where there is much diurnal inequality in the tides, the amount of rise and fall can not be depended upon, and additional caution is necessary.

A careful distinction should be made between the vertical *rise and fall* of the tide, which is marked at the transition periods by a stationary height, or *stand*, and the tidal current, which is the horizontal transfer of water as a result of the difference of level, producing the *flood and ebb*, and the intermediate condition, or *slack*. It seldom occurs that the turn of the tidal stream is exactly coincident with the high and low water, and in some channels the current may outlast the vertical movement which produces it by as much as three hours, the effect being that when the water is at a stand the tidal stream is at its maximum, and when the current is slack the rise or fall is going on with its greatest rapidity. Care must be taken to avoid confounding the two.

The effect of the tidal wave in causing currents may be illustrated by two simple cases:

(1) Where there is a small tidal basin connected with the sea by a large opening.

(2) Where there is a large tidal basin connected with the sea by a small opening.

In the first case the velocity of the current in the opening will have its maximum value when the height of the tide within is changing most rapidly, i. e., at a time about midway between high and low water. The water in the basin keeps at approximately the same level as the water outside. The flood stream corresponds with the rising and the ebb with the falling of the tide.

In the second case the velocity of the current in the opening will have its maximum value when it is high water or low water without, for then there is the greatest head of water for producing motion. The flood stream begins about three hours after low water, and the ebb stream about three hours after high water, slack water thus occurring about midway between the tides.

Along most shores which lack features like bays and tidal rivers, the current usually turns soon after high water and low water.

The swiftest current in straight portions of tidal rivers is usually in the middle of the stream, but in curved portions the most rapid current is toward the outer edge of the curve, and here the water will be deepest. The pilot rule for best water is to follow the ebb-tide reaches.

Countercurrents and eddies may occur near the the shores of straits, especially in bights and near points. A knowledge of them is useful in order that they may be taken advantage of or avoided.

A swift current often occurs in the narrow passage connecting two large bodies of water, owing to their considerable difference of level at the same instant. The several passages between Vineyard Sound and Buzzards Bay are cases in point. In the Woods Hole Passage the maximum strength of the tidal streams occurs near high and low water.

Tide rips are made by a rapid current setting over an irregular bottom, as at the edges of banks where the change of depth is considerable.

Generally speaking, the rise and fall and strength of current are at their minimum along straight stretches of coast upon the open ocean, while bays, bights, inlets, and large rivers operate to augment the tidal effects, and it is in the vicinity of these that one finds the highest tides and strongest currents. The navigator need therefore not be surprised in cruising along a coast to notice that his vessel is set more strongly toward or from the shore in passing an indentation, and that the evidences of tide will appear more marked as he nears its mouth. Usually more complete data are furnished in charts and tide tables regarding the rise and fall, and it frequently occurs that the information regarding the tidal current is comparatively meager; the mariner must therefore take every means to ascertain for himself the direction and force of the tidal and other currents, either from the set shown between successive well-located positions of the ship, or by noting the ripple of the water around buoys, islets, or shoals, the direction in which vessels at anchor are riding, and the various other visible effects of the current.

Current arrows on the chart must not be regarded as indicating absolutely the conditions that are to be encountered. They represent the mean of the direction and force observed, but the observations upon which they are based may not be complete, or there may be reasons that bring about a departure from the normal state.

165. Charts.—The chart should be carefully studied, and among other things all of its notes should be read, as valuable information may be given in the margin which it is not practicable to place upon the chart abreast the locality affected.

The mariner will do well to consider the source of his chart and the authority upon which it is based. He will naturally feel the greatest confidence in a chart issued by the Government of one of the more important maritime nations which maintains a well-equipped office for the especial purpose of acquiring and treating hydrographic information. He should note the character of the survey from which the chart has been constructed; and, finally, he should be especially careful that the chart is of recent issue or bears correction of a recent date—facts that should always be clearly shown upon its face.

It is well to proceed with caution when the chart of the locality is based upon an old survey, or one whose source does not carry with it the presumption of accuracy. Even if the original survey was a good one, a sandy bottom, in a region where the currents are strong or the seas heavy, is liable to undergo in time marked changes; and where the depth is affected by the deposit or removal of silt, as in the vicinity of the estuaries of large river systems, the behavior is sometimes most capricious. Large blank spaces on the chart, where no soundings are shown, may be taken as an indication that no soundings were made, and are to be regarded with suspicion, especially if the region abounds in reefs or pinnacle rocks, in which case only the closest sort of a survey can be considered as revealing all the dangers. All of these facts must be duly weighed.

When navigating by landmarks the chart of the locality which is on the largest scale should be used. The hydrography and topography in such charts appear in greater detail, and—a most important consideration—bearings and angles may be plotted with increased accuracy.

To sum up, the navigator must know the exact draft of the ship when approaching the land. He must make himself familiar with every detail of the charts he will be required to use and must read the charts in such a way as to be able to form a mental picture of how the land and the various aids to navigation will look when sighted, remembering that the position of the sun at different times of day, or the position of the moon at night, affects the appearance of the land as presented to the navigator approaching from seaward. He must be thoroughly familiar with the day, night, and fog characteristics of all aids to navigation in the locality. He must know the state of the tide and the force and direction of the current at all times when in pilot waters. The navigator, in making his plan for entering a strange port, should give very careful previous study to the chart, and should carefully select what appear to be the most suitable marks for use, also providing himself with substitutes for use in case those selected as most suitable should prove unreliable by not being recognized with absolute certainty. It must be remembered that buoys seen at a distance, in approaching a channel, are often difficult to place or identify, because all may appear equally distant, though in reality far apart. Ranges should be noted, if possible, and the lines drawn, both for leading through the best water in channels and also for guarding against particular dangers. For the latter purpose, safety bearings should in all cases be laid down where no suitable ranges offer. The courses to be steered in entering should also be laid down and distances marked thereon. If intending to use the sextant and danger angle in passing dangers, and especially in passing between dangers, the danger circles should be plotted and regular courses planned, rather than to run haphazard by the indications of the angle alone, with the possible trouble to be apprehended from wild steering at critical points.

The ship's position should not be allowed to be in doubt at any time, even in entering ports considered safe and easy of access, and should be constantly checked by continuing to use for this purpose those marks concerning which there can be no doubt until others are unmistakably recognized.

The ship should ordinarily steer exact courses and follow exact lines as planned from the chart, changing course at exact points, and, where the distances are considerable, her position on the line should be checked at frequent intervals, recording the time and the reading of the patent log. This is desirable, even where it may seem unnecessary for safety; because, if running by the eye alone and the ship's exact position be suddenly required, as in a sudden squall, fixing at that particular moment might be impossible.

The habit of running exact courses with precise changes of courses will be found most useful when it is desired to enter port or pass through inclosed waters during fog by means of the buoys; here safety demands that the buoys be made successively, to do which requires, if the fog be dense, very accurate courses and careful attention to the times, rate of speed, and the set of the current. Failure to make a buoy as expected leaves no safe alternative but to anchor at once.

It is a useful point to remember that in passing between dangers where there are no suitable leading marks, as, for instance, between two islands or an island and the main shore, with dangers extending from both, a mid-channel course may be steered by the eye alone with great accuracy, as the eye is able to estimate very closely the position midway between visible objects.

In piloting among coral reefs or banks, a time should be chosen when the sun will be astern, conning the vessel from aloft or from an elevated position forward. The line of demarcation between the deep water and the edges of the shoals, which generally show as green patches, is indicated with surprising clearness. This method is of frequent application in the numerous passages of the Florida keys.

Changes of course should in general be made by exact amounts, naming the new course or the amount of the change desired, rather than by ordering the helm to be put over and then steadying when on the desired heading, with the possibility of the attention being diverted and so forgetting in the meantime that the ship is still swinging. The helmsman, knowing just what is desired and the amount of change to be made, is thus enabled to act more intelligently and to avoid wild steering, which in narrow channels is a very positive source of danger.

Coast piloting involves the same principles and requires that the ship's positions be continuously determined or checked as the landmarks are passed. On well-surveyed coasts there is a great advantage in keeping near the land, thus holding on to the marks and the soundings, and thereby knowing at all times the position, rather than keeping offshore and losing the marks, with the necessity of again making the land from vague positions, and perhaps the added inconvenience of fog or bad weather, involving a serious loss of time and fuel.

The route should be planned for normal conditions of weather with suitable variations where necessary in case of fog or bad weather or making points at night, the courses and distances, in case of regular runs over the same route, being entered in a notebook for ready reference, as well as laid down on the chart. The danger circles for either the horizontal or the vertical danger angles should be plotted, wherever the method can be usefully employed, and the angles marked thereon; many a mile may thus be saved in rounding dangerous points, with no sacrifice in safety. Ranges should also be marked in, where useful for positions or for safety, and also to use in checking the deviation of the compass by comparing, in crossing, the compass bearing of the range with its magnetic bearing, as given by the chart.

Changes of course will in general be made with mark or object abeam, the position (a new "departure") being then, as a rule, best and most easily obtained.

In making the land in a fog the sounding machine must be kept going at intervals of half an hour some hours before it is expected that soundings can be obtained. Several soundings taken at random will not locate a ship, but on the contrary may lead to disaster. In using the sounding machine be careful that the man handling the tube does not invert the tube when taking it from the tube case, as this would allow water to run toward the closed end of the tube, causing a discoloration of the coating and thus bring about an incorrect sounding. It is also essential that the lead be cleanly and freshly armed for each cast. The bottom having been picked up, a graphic record of the soundings may be laid down in the manner previously described in paragraph 160 and an approximation made of the position of the ship. Keep a sharp lookout for any landmarks that might show up during a momentary lifting of the fog and have keen ears listening for an aerial or submarine fog signal. Having picked up any such signal, make sure to ascertain exactly what landmark it is. From now on proceed with caution and determine whether it is better to anchor or to proceed through the harbor channel in the fog. If, having approached the land and failed to hear fog signals at the time they were expected to be heard and the soundings indicate a dangerous proximity to shore, the only safe course is either to anchor or to stand off. When running slowly in a fog (which caution, as well as the law, requires that one should do) it must be borne in mind that the relative effect of current is increased; for instance, the angle of deflection from the course caused by a cross set is greater at low than at high speed. It is worth remembering that when in the vicinity of a bold bluff shore vessels are sometimes warned of a too-close approach by having their own fog signals echoed back from the cliffs; indeed, from a knowledge of the velocity of sound it is possible to gain some rough idea of the distance in such a case.. Great caution must be used in approaching a bold coast in a fog and, unless soundings can be got that will reasonably assure the navigator of his distance from the coast, the only safe course is to stand off, if the depth of the water does not permit of anchoring.

The best aids at the disposal of the navigator when running in a fog are the sounding machine and the hand lead, and the navigator will do well to make great use of them. Even in clear weather the sounding machine may be a great aid to the navigator in verifying his position.

In approaching the land and entering harbors, the navigator must bear in mind that rules of the road in inland waters sometimes differ from those used on the high sea, and should inform himself of the boundaries of the waters where different rules of the road obtain.

166. Records.—It will be found a profitable practice to pay careful attention to the recording of the various matter relating to the piloting of the ship. A notebook should be kept at hand on deck or on the bridge, in which are to be entered all bearings or angles taken to fix the position, all changes of course, important soundings, and any other facts bearing upon the navigation. (This book should be different from the one in which astronomical sights and offshore navigation are worked.) The entries, though in memorandum form, should be complete; it should be clear whether bearings and courses are true, magnetic, or by compass; and it is especially important that the time and patent log reading should be given for each item recorded. The value of this book will make itself apparent in various directions; it will afford accurate data for the writing of the ship's log; it will furnish interesting information for the next run over the same ground; it will provide a means by which, if the ship be shut in by fog, rain, or darkness, or if there be difficulty in recognizing landmarks ahead, the last accurate fix can be plotted and brought forward; and, finally, if there should be a mishap, the notebook would furnish evidence as to where the trouble has been.

The chart on which the work is done should also be made an intelligible record, and to this end the pencil marks and lines should not be needlessly numerous, heavy, or, long. In plotting bearings, draw lines only long enough to cover the probable position. Mark intersections or positions by drawing a small circle around them, and writing neatly abreast them the time and patent log reading. Indicate the courses and danger bearings by full lines and mark them appropriately, preferably giving both magnetic (or true) and compass directions. A great number of lines extending in every direction may lead to confusion; however remote the chance may seem, the responsibilities of piloting are too serious to run even a small risk.

Finally, on anchoring, record and plot the position by bearings or angles taken after coming to; observe that the berth is a safe one, or, if in doubt, send a boat to sound in the vicinity of the ship to make sure.

CHAPTER V.

THE SAILINGS.

167. In considering a ship's position at sea with reference to any other place, either one that has been left or one toward which the vessel is bound, five terms are involved—the *Course*, the *Distance*, the *Difference of Latitude*, the *Difference of Longitude*, and the *Departure*.[a] The solutions of the various problems that arise from the mutual relation of these quantities are called *Sailings*.

168. Kinds of Sailings.—When the only quantities involved are the course, distance, difference of latitude, and departure, the process is denominated *Plane Sailing*. In this method the earth is regarded as a plane, and the operation proceeds as if the vessel sailed always on a perfectly level surface. When two or more courses are thus considered, they are combined by the method of *Traverse Sailing*. It is evident that the number of *miles* of latitude and departure can thus be readily deduced; but, while one mile always equals one minute in difference of latitude, one mile of departure corresponds to a difference of longitude that will vary with the latitude in which the vessel is sailing. Plane sailing therefore furnishes no solution where difference of longitude is considered, and for such solution resort must be had to one of several methods, which, by reason of their taking account of the spherical figure of the earth, are called *Spherical Sailings*.

When a vessel sails on an east or west course along a parallel of latitude, the method of converting departure into difference of longitude is called *Parallel Sailing*. When the course is not east or west, and thus carries the vessel through various latitudes, the conversion may be made either by *Middle Latitude Sailing*, in which it is assumed that the whole run has been made in the mean latitude, or by *Mercator Sailing*, in which the principle involved in the construction of the Mercator chart (art. 39, Chap. II) is utilized.

Great Circle Sailing deals with the courses and distances between any two points when the track followed is a great circle of the terrestrial sphere. A modification of this method which is adopted under certain circumstances is called *Composite Sailing*.

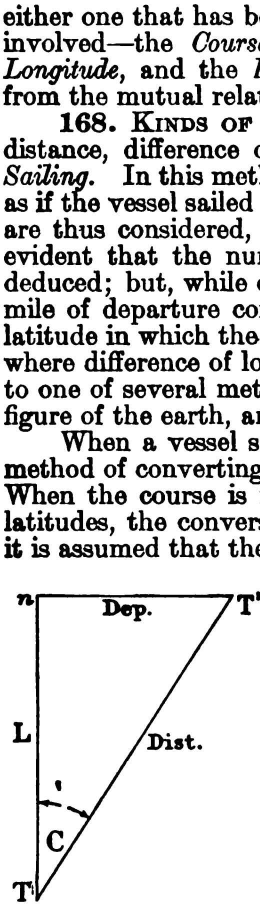

Fig. 24.

PLANE SAILING.

169. In Plane Sailing, the curvature of the earth being neglected, the relation between the elements of the rhumb track joining any two points may be considered from the plane right triangle formed by the meridian of the place left, the parallel of the place arrived at, and the rhumb line. In figure 24, T is the point of departure; T′, the point of destination; T*n*, the meridian of departure; T′*n*, the parallel of destination; and TT′, the rhumb line between the points. Let C represent the course, T′T*n;* Dist., the distance, TT′; DL, the difference of latitude, T*n;* and Dep., the departure, T′*n*. Then from the triangle TT′*n*, we have the following:

$$\sin C = \frac{\text{Dep.}}{\text{Dist.}};$$

$$\cos C = \frac{\text{D L}}{\text{Dist.}};$$

$$\tan C = \frac{\text{Dep.}}{\text{D L}}.$$

[a] For the definition of these terms, see article 6, Chapter I.

From these equations are derived the following formulæ for working the various problems that may arise in Plane Sailing:

Given.	Required.	Formulæ.	
Course and distance	Difference of latitude	D L = Dist. cos C.	Log D L = log Dist. + log cos C.
	Departure	Dep. = Dist. sin C.	Log Dep. = log Dist. + log sin C.
Difference of latitude and departure.	Course	$\text{Tan } C = \frac{\text{Dep.}}{\text{D L}}$.	Log tan C = log Dep. − log D L.
	Distance	$\text{Dist.} = \frac{\text{Dep.}}{\sin C}$.	Log Dist. = log Dep. − log sin C.
Course and difference of latitude.	Distance	$\text{Dist.} = \frac{\text{D L}}{\cos C}$.	Log Dist. = log D L − log cos C.
	Departure	Dep. = D L tan C.	Log Dep. = log D L + log tan C.
Course and departure	Distance	$\text{Dist.} = \frac{\text{Dep.}}{\sin C}$.	Log Dist. = log Dep. − log sin C.
	Difference of latitude	$\text{D L} = \frac{\text{Dep.}}{\tan C}$.	Log D L = log Dep. − log tan C.
Distance and difference of latitude.	Course	$\text{Cos } C = \frac{\text{D L}}{\text{Dist.}}$.	Log cos C = log D L − log Dist.
	Departure	Dep. = Dist. sin C.	Log Dep. = log Dist. + log sin C.
Distance and departure.	Course	$\text{Sin } C = \frac{\text{Dep.}}{\text{Dist.}}$.	Log sin C = log Dep. − log Dist.
	Difference of latitude.	D L = Dist. cos C.	Log D L = log Dist. + log cos C.

170. The solution of the plane right triangle may be accomplished either by Plane Trigonometry, by Traverse Tables, or by construction. If the former method is adopted, the logarithms of numbers may be found in Table 42, and of the functions of angles in Table 44. A more expeditious method is available, however, in the Traverse Tables, which give by inspection the various solutions. Table 1 contains values of the various parts for each unit of Dist. from 1 to 300, and for each quarter-point (2° 49′), of C; Table 2 contains values for each unit of Dist. from 1 to 600, and for each degree of C. The method of solving by construction consists in laying down the various given terms by scale upon a chart or plain paper, and measuring thereon the terms required.

171. Of the various problems that may arise, the first two given in the foregoing table are of much the most frequent occurrence. In the first, the given quantities are course and distance, and those to be found are difference of latitude and departure; this is the case where a navigator, knowing the distance run on a given course, desires to ascertain the amount made good to north or south and to east or west. In the second case the conditions are reversed; this arises where the course and distance between two points are to be obtained from their known difference of latitude and departure.

EXAMPLE: A ship sails SW. by W., 244 miles. Required the difference of latitude and the departure made good.

By Computation.

Dist.	244	log	2.38739
C	56° 15′	log cos	9.74474
DL	135.6	log	2.13213
Dist.	244	log	2.38739
C	56° 15′	log sin	9.91985
Dep.	202.9	log	2.30724

By Inspection.

In Table 1, find the course SW. by W. (5 points); it occurs at the bottom of the page, therefore take the names of the columns from the bottom as well; opposite 244 in the Dist. column will be seen Lat. 135.6 and Dep. 202.9.

EXAMPLE: A ship sails N. 5° E., 188 miles. Required the difference of latitude and the departure.

By Computation.

Dist.	188	log	2. 27416
C	5°	log cos	9. 99834
DL	187. 3	log	2. 27250
Dist.	188	log	2. 27416
C	5°	log sin	8. 94030
Dep.	16. 4	log	1. 21446

By Inspection.

In Table 2, find the course 5°; it occurs at the top of the page, therefore take the names of the columns from the top; opposite 188 in the Dist. column will be seen Lat. 187.3 and Dep. 16.4.

EXAMPLE: A vessel is bound to a port which is 136 miles to the north and 203 miles to the west of her position. Required the course and distance.

By Computation.

Dep.	203	log	2. 30750
DL	136	log	2. 13354
C	(N.) 56° 11′ (W.)	log tan	0. 17396
Dep.	203	log	2. 30750
C	56° 11′	log sin	9. 91951
Dist.	244. 3	log	2. 38799

By Inspection.

Enter Table 1 and turn the pages until a course is found whereon the numbers 136 and 203 are found abreast each other in the columns marked respectively Lat. and Dep. This occurs most nearly at the course for 5 points, the angle being taken from the bottom, because the appropriate names of the columns are found there. The course is therefore NW. by W. Interpolating for intermediate values, the corresponding number in the Dist. column is about 244.3.

EXAMPLE: As a result of a day's run a vessel changes latitude 244 miles to the south and makes a departure of 171 miles to the east. What is the course and distance made good?

By Computation.

Dep.	171	log	2. 23300
DL	244	log	2. 38739
C	(S.) 35° 02′ (E.)	log tan	9. 84561
Dep.	171	log	2. 23300
C	35° 02′	log sin	9. 75895
Dist.	297. 9	log	2. 47405

By Inspection.

Enter Table 2 and the nearest agreement will be found on course (S.) 35° (E.), the appropriate names being found at the top of the page. The nearest corresponding Dist. is 298 miles.

TRAVERSE SAILING.

172. A *Traverse* is an irregular track made by a ship in sailing on several different courses, and the method of *Traverse Sailing* consists in finding the difference of latitude and departure corresponding to several courses and distances and reducing all to a single equivalent course and distance. This is done by determining the distance to north or south and to east or west made good on each course, taking the algebraic sum of these various differences of latitude and departure and finding the course and distance corresponding thereto. The work can be most expeditiously performed by adopting a tabular form for the computation and using the traverse tables.

EXAMPLE: A ship sails SSE., 15 miles; SE., 34 miles; W. by S., 16 miles; WNW., 39 miles; S. by E., 40 miles. Required the course and distance made good.

Courses.	Dist.	N.	S.	E.	W.
SSE.	15		13. 9	5. 7	
SE.	34		24. 0	24. 0	
W. by S.	16		3. 1		15. 7
WNW.	39	14. 9			36. 0
S. by E.	40		39. 2	7. 8	
		14. 9	80. 2	37. 5	51. 7
			14. 9		37. 5
S. by W.	66. 8		65. 3		14. 2

The result of the various courses is, therefore, to carry the vessel S. by W., 66.8 miles from her original position.

PARALLEL SAILING.

173. Thus far the earth has been regarded as an extended plane, and its spherical figure has not been taken into account; it has thus been impossible to consider one of the important terms involved—namely, difference of longitude. *Parallel Sailing* is the simplest of the various forms of Spherical Sailing, being the method of interconverting departure and difference of longitude when the ship sails upon an east or west course, and therefore remains always on the same parallel of latitude.

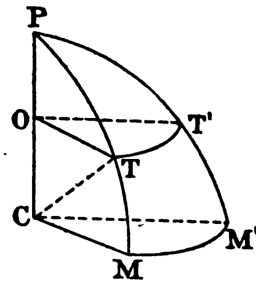

FIG. 25.

In figure 25, T and T′ are two places in the same latitude; P, the adjacent pole; TT′, the arc of the parallel of latitude through the two places; MM′, the corresponding arc of the equator intercepted between their meridians PM and PM′; and TT′, the departure on the parallel whose latitude is TCM = OTC, and whose radius is OT.

Let D.Lo represent the arc of the equator MM′, which is the measure of MPM′, the difference of longitude of the meridians PM and PM′; R, the equatorial radius of the earth, CM = CT; r, the radius OT of the parallel TT′; and L, the latitude of that parallel.

Then, since TT′ and MM′ are similar arcs of two circles, and are therefore proportional to the radii of the circles, we have:

$$\frac{TT'}{MM'} = \frac{OT}{CM}; \text{ or, } \frac{\text{Dep.}}{\text{D.Lo}} = \frac{r}{R}.$$

From the triangle COT, $r = R \cos L$; hence

$$\frac{\text{Dep.}}{\text{D.Lo}} = \frac{R \cos L}{R}; \text{ or, D.Lo} = \text{Dep. sec. L; or, Dep.} = \text{D.Lo} \cos L.$$

Thus the relations are expressed between *minutes* of longitude and *miles* of departure.

174. Two cases arise under Parallel Sailing: First, where the difference of longitude between two places on the same parallel is given, to find the departure; and, second, where the departure is given, to find the difference of longitude.

In working these problems, the computation can be made by logarithms; but the traverse tables may more conveniently be employed. Remembering that those tables are based upon the formulæ,

$$\text{DL} = \text{Dist. } \cos C, \text{ and Dist.} = \text{DL } \sec C,$$

we may substitute for the column marked Lat. the departure, for that marked Dist. the difference of longitude, and for the courses at top and bottom of the page the latitude. The tables then become available for making the required conversions.

EXAMPLE: A ship in the latitude of 49° 30′ sails directly east until making good a difference of longitude of 3° 30′. Required the departure.

By Computation.

L	49° 30′	log cos	9.81254
D.Lo.	210′	log	2.32222
Dep.	136.4	log	2.13476

By Inspection.

Enter Table 2 with the latitude as C and the difference of longitude as Dist. As the table is calculated only to single degrees, we must find the numbers in the pages of 49° and 50° and take the mean. Corresponding to Dist. 210 in the former is Lat. 137.8, and in the latter Lat. 135.0. The mean, which is the required departure, is 136.4.

EXAMPLE: A ship in the latitude of 38° sails due west a distance of 215.5 miles. Required the difference of longitude.

By Computation.

L	38°	log sec	0.10347
Dep.	215.5	log	2.33345
D.Lo	273′.5	log	2.43692
	4° 33′.5		

By Inspection.

Entering Table 2 with the latitude, 38°, as a course, corresponding with the number 215.5 in column of Lat., is 273.5 in the column of Dist. This is therefore the required difference of longitude, being equal to 4° 33′.5.

MIDDLE LATITUDE SAILING.

175. When a ship follows a course obliquely across the meridian the latitude is constantly changing, and the method of converting departure and difference of longitude by Parallel Sailing, just described, ceases to be applicable.

In figure 26, T is the point of departure; T′, the point of destination; P, the earth's pole; TT′, the rhumb track; n_1TT′, the course; Tn, n_1T′, the respective parallels of latitude; and MM′, the equator.

The difference of longitude between T and T′ is MPM′, which may be measured by the arc of the equator, MM′, intercepted between their meridians. This corresponds to a departure Tn in the latitude of T, and to the smaller departure T′n_1 in the higher latitude of T′; but since the vessel neither makes all of the departure in the latitude T, nor all of it in the latitude T′, the departure actually made in the passage must have some intermediate value between these extremes. Dividing the total difference of longitude into a number of equal parts MPm_1, m_1Pm_2, etc., of such small extent that, for the purposes of conversion, the change of latitude corresponding to each may be neglected, we have the total departure made up of the sum of a number of small departures, each equal to the same difference of longitude, but each different from the other. These will be d_1r_1 in the latitude T, d_2r_2 in the latitude r_1, etc. Hence we have:

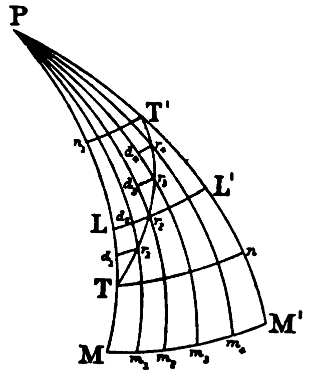

FIG. 26.

$$MM' = d_1r_1 \sec MT + d_2r_2, \sec m_1r_1 + d_3r_3, \sec m_2r_2, + \text{etc.}$$

Now, if LL′ be a parallel of latitude lying midway between Tn and T′n_1, since there will be as many of the small parts lying above as below it, and since for moderate distances the ratio to be employed in the conversion of departure and difference of longitude may be regarded as varying directly with the latitude, it may be assumed for such distances that the sum of all of the different small departures equals the single departure between the meridians measured in the latitude LL′, and therefore that the departure obtained by the method of plane sailing on any course may be converted into difference of longitude by multiplying by the secant of the Middle Latitude.

The method of conversion based upon this assumption is denominated *Middle Latitude Sailing*, and by reason of its convenience and simplicity is usually employed for short distances, such as those covered by a vessel in a day's run.

176. In Middle Latitude Sailing, having found the mean of the latitudes, the solution is identical with that of Parallel Sailing (art. 173), substituting the Middle Latitude for the single latitude therein employed.

EXAMPLE: A ship in Lat. 42° 30′ N., Long. 58° 51′ W., sails SE. by S., 300 miles. Required the latitude and longitude arrived at.

From Table 1: Course SE. by S., Dist., 300, we find Lat., 249.4 S. (4° 09′.4), Dep., 166.7 E.

Latitude left,	42° 30′.0 N.	Latitude left,	42° 30′ N.
DL,	4 09 .4 S.	Latitude arrived at,	38 21 N.
Latitude arrived at,	38 20 .6 N.		2)80 51
		Mid. latitude,	40 25 N.

Enter Table 2 with the middle latitude, 40°, as a course; the difference of longitude (Dist.) corresponding to the departure (Lat.) 166.7 is 217.6; entering with 41°, it is 220.9; the mean is 219.2 (3° 39′.2).

Longitude left,	58° 51′.0 W.
D.Lo,	3 39 .2 E.
Longitude arrived at,	55 11 .8 W.

EXAMPLE: A ship in Lat. 39° 42′ S., Long. 3° 31′ E., sails S. 42° W., 236 miles. Required the latitude and longitude arrived at.

From Table 2: Course, S. 42° W., Dist., 236 miles; we find Lat., 175.4 S. (2° 55′.4), Dep., 157.9 W.

Latitude left,	39° 42′.0 S.	Latitude left,	39° 42′ S
DL,	2 55 .4 S.	Latitude arrived at,	42 37 S.
Latitude arrived at,	42 37 .4 S.		2)82 19
		Mid. latitude,	41 09 S.

From Table 2: Mid. Lat. (course), 41°, Dep. (Lat.), 157.9; we find D.Lo (Dist.), 209.3 (3° 29′.3).

Longitude left,	3° 31′.0 E.
D.Lo,	3 29 .3 W.
Longitude arrived at,	0 01 .7 E.

EXAMPLE: A vessel leaves Lat. 49° 57′ N., Long. 15° 16′ W., and arrives at Lat. 47° 18′ N., Long. 20° 10′ W. Required the course and distance made good.

Latitude left	49° 57′ N.	Longitude left,	15° 16′ W.
Latitude arrived at,	47 18 N.	Longitude arrived at,	20 10 W.
DL,	{2° 39′ / 159′} S.	D.Lo,	{4° 54′ / 294′} W.
	2)97° 15′ N.		
Mid. latitude,	48 38 N.		

From Table 2: Mid. Lat. (course), 49°, D.Lo (Dist.), 294; we find Dep. (Lat.), 192.9.
From Table 2: DL 159 S., Dep. 192.9 W., we find course S. 51° W., Dist., 251 miles.

177. It may be remarked that the Middle Latitude should not be used when the latitudes are of opposite name; if of different names and the distance is small, the departure may be assumed equal to the difference of longitude, since the meridians are sensibly parallel near the equator; but if the distance is great the two portions of the track on opposites of the equator must be treated separately.

178. The assumption upon which Middle Latitude sailing is based—that the conversion may be made as if the whole distance were sailed upon a parallel midway between the latitudes of departure and destination—while sufficiently accurate for moderate distances, may be materially in error where the distances are large. In such case, either the method of Mercator Sailing (art. 179) must be employed, or else the correction given in the following table should be applied to the mean latitude to obtain what may be termed the latitude of conversion, being that latitude in which the required conditions are accurately fulfilled. The table is computed from the formulae:

$$\cos L_c = \frac{l}{m},$$

$$\text{correction} = L_c - L_o = \cos^{-1}\frac{l}{m} - L_o$$

where L_c represents the latitude of conversion, L_o the mean latitude, and l and m are respectively the differences of latitude and of meridional parts (art. 40, Chap. II) between the latitudes of departure and destination.[a]

Mid. Lat.	*Difference of latitude.* 1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	12°	14°	16°	18°	20°	Mid. Lat.
°	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	°
15	−86	−85	−84	−83	−81	−79	−76	−73	−69	−65	−56	−46	−34	−21	− 6	15
18	−67	−67	−66	−65	−63	−61	−59	−56	−53	−50	−43	−34	−23	−12	1	18
21	−54	−54	−53	−52	−51	−49	−47	−44	−42	−39	−32	−24	−15	− 5	7	21
24	−44	−44	−44	−42	−41	−40	−38	−36	−33	−31	−24	−17	− 8	1	12	24
30	−31	−30	−29	−29	−28	−26	−24	−23	−20	−18	−12	− 6	1	11	21	30
35	−23	−22	−21	−21	−19	−18	−17	−15	−12	−10	− 5	2	10	18	28	35
40	−17	−16	−15	−14	−13	−12	−10	− 8	− 6	− 4	2	8	16	25	34	40
45	−12	−11	−11	−10	− 8	− 7	− 5	− 3	− 1	1	7	14	22	31	41	45
50	− 8	− 8	− 7	− 6	− 5	− 3	− 1	1	3	6	12	20	28	38	49	50
55	− 5	− 5	− 4	− 3	− 2	0	2	5	7	10	17	25	35	46	58	55
58	− 4	− 3	− 3	− 1	0	2	4	7	10	13	20	29	39	51	64	58
60	− 3	− 3	− 2	− 1	1	3	5	8	11	14	22	32	43	55	69	60
62	− 3	− 2	− 1	0	2	4	7	9	13	17	25	35	46	60	75	62
64	− 2	− 1	0	1	3	5	8	11	14	18	27	38	50	65	81	64
66	− 2	− 1	0	2	4	6	9	12	16	20	30	42	55	71	89	66
68	− 1	0	1	2	5	7	10	14	18	22	33	46	61	78	98	68
70	− 1	0	1	3	5	8	12	16	20	25	37	51	67	87	109	70
72	0	0	2	4	6	10	13	18	23	28	41	57	76	97	123	72

[a] The statement often made that the latitude of conversion is always greater than the middle latitude is not correct when the compression of the earth is taken into account, as an inspection of the table will show; that statement is based upon an assumption that the earth is a perfect sphere, and it was upon that assumption that a table which appeared in early editions of this work was computed. The value of the compression adopted for this table is $\frac{1}{293.465}$.

EXAMPLE: A vessel sails from Lat. 10° 13′ S. to Lat. 20° 21′ S., making a departure of 432 miles. Required the difference of longitude.

Latitude left,	10° 13′ S.					
Latitude arrived at,	20 21 S.					
	2)30 34	For Mid. Lat. 15° and Diff. of Lat. 10°. Correction, −65′.				
Mid. latitude,	15 17 S.					
Correction,	− 1 05					
L_c,	14 12 S.					
		L_c	14° 12′	log sec	.01348	
		Dep.	432	log	2.63548	
		D.Lo	445′.6	log	2.64896	

MERCATOR SAILING.

179. *Mercator Sailing* is the method by which values of the various elements are determined from considering them in the relation in which they are plotted upon a chart constructed according to the Mercator projection.

180. Upon the Mercator chart (art. 39, Chap. II), the meridians being parallel, the arc of a parallel of latitude is shown as equal to the corresponding arc of the equator; the length of every such arc is, therefore, expanded; and, in order that the rhumb line may appear as a straight line, the meridians are also expanded by such amount as is necessary to preserve, in any latitude, the proper proportion existing between a unit of latitude and a unit of longitude. The length of small portions of the meridian thus increased are called *meridional parts* (art. 40, Chap. II), and these, computed for every minute of latitude from 0° to 80°, form the Table of Meridional Parts (Table 3), by means of which a Mercator chart may be constructed and all problems of Mercator Sailing may be solved.

In the triangle ABC (fig. 27), the angle ACB is the course, C; the side AC, the distance, Dist.; the side BC, the difference of latitude, DL; and the side AB, the departure, Dep. Then corresponding to the difference of latitude BC in the latitude under consideration, if CE be laid off to represent the meridional difference of latitude, m, completing the right triangle CEF, EF will represent the difference of longitude, D.Lo. The triangle ABC gives the relations involved in Plane Sailing as previously described; the triangle CEF affords the means for the conversion of departure and difference of longitude by Mercator Sailing.

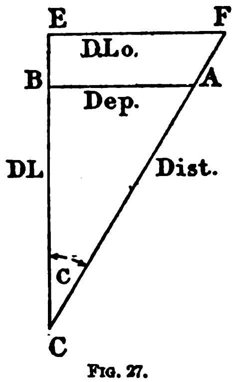

FIG. 27.

181. To find the arc of the expanded meridian intercepted between any two parallels, or the *meridional difference of latitude*, when both places are on the same side of the equator, subtract the meridional parts of the lesser latitude, as given by Table 3, from the meridional parts of the greater; the remainder will be the meridional difference of latitude; but if the places are on different sides of the equator, the sum of the meridional parts will be the meridional difference of latitude.

182. To solve the triangle CEF by the traverse tables it is only necessary to substitute meridional difference for Lat., and difference of longitude for Dep. Where long distances are involved, carrying the computation beyond the limits of the traverse table, as frequently occurs in this method, either of two means may be adopted: the problems may be worked by trigonometrical formulæ, using logarithms or the given quantities involved may all be reduced by a common divisor until they fall within the traverse table, and the results, when obtained, correspondingly increased. The former method is generally preferable, especially when the distances are quite large and accurate results are sought. The formulæ for the various conversions are as follows:

$$\tan C = \frac{D.Lo}{m}; \quad D.Lo = m \tan C; \quad m = D.Lo \cot C.$$

EXAMPLE: A ship in Lat. 42° 30′ N., Long. 58° 51′ W., sails SE. by S., 300 miles. Required the latitude and longitude arrived at.

From Table 1: Course, SE. by S., Dist., 300; we find Lat. 249.4 S. (4° 09′.4).

Latitude left,	42° 30′.0 N.	Merid. parts,	+2806.4
DL,	4 09 .4 S.		
Latitude arrived at,	38 20 .6 N.	Merid. parts,	−2480.4
		m,	326.0

By Computation.

m	326.0	log	2.51322
C	33° 45′	log tan	9.82489
D.Lo	217′.8 / 3° 37′.8	log	2.33811

By Inspection.

Enter Table 1, course 3 points; since the quantities involved exceed the limits of the table, divide by 2; abreast $\frac{m}{2}$ (Lat.), 163.0, find $\frac{\text{D.Lo}}{2}$ (Dep.), 108.9; hence D.Lo=217′.8 or 3° 37′.8.

Longitude left,	58° 51′.0 W.
D.Lo,	3 37 .8 E.
Longitude arrived at,	55 13 .2 W.

EXAMPLE: A ship in Lat. 4° 37′ S., Long. 21° 05′ W., sails N. 14° W., 450 miles. Required the latitude and longitude arrived at.

From Table 2: Course, (N.) 14° (W.), Dist., 450; we find Lat. 436.6 N. (7° 16′.6).

Latitude left,	4° 37′.0 S.	Merid. parts,	+275.4
DL,	7 16 .6 N.		
Latitude arrived at,	2 39 .6 N.	Merid. parts,	+159.0
		m,	434.4

By Computation.

m	434.4	log	2.63789
C	14°	log tan	9.39677
D.Lo	108′.3 / 1° 48′.3	log	2.03466

By Inspection.

From Table 2: Course, 14°, m (Lat.), 434.4, we find D.Lo (Dep.) 108′.3 W., or 1° 48′.3.

Longitude left,	21° 05′.0 W.
D.Lo,	1 48 .3 W.
Longitude arrived at,	22 53 .3 W.

EXAMPLE: Required the course and distance by rhumb line from a point in Lat. 42° 03′ N., Long. 70° 04′ W., to another in Lat. 36° 59′ N., Long. 25° 10′ W.

Lat. departure,	42° 03′ N.	Merid. pts.,	+2770.1	Long. departure,	70° 04′ W.
Lat. destination,	36 59 N.	Merid. pts.,	−2377.3	Long. destination,	25 10 W.
DL	5° 04′ / 304′ S.	m,	392.8	D.Lo	44° 54′ / 2694′ E.
D.Lo	2694	log	3.43040		
m	392.8	log	2.59417		
C (S.) 81° 42′ (E.)		log tan	.83623	log sec.	.84056
DL	304′			log	2.48287
Dist.	2106			log	3.32343

The course is therefore S. 81° 42′ E., and the distance is 2,106 miles. Since the figures involved are so large, it is best to employ only the method by computation. The formula by which the Dist. is obtained comes from Plane Sailing.

GREAT CIRCLE SAILING.

183. The shortest distance between any two points on the earth's surface is measured by the arc of the great circle which passes through those points; and the method of sailing in which the arc of a great circle is employed for the track of the vessel, taking advantage of the fact that it is the shortest route possible, is denominated *Great Circle Sailing*.

184. It frequently happens when a great circle route is laid down that it is found to lead across the land, or to carry the vessel into a region of dangerous navigation or extreme cold which it is expedient to avoid; in such a case a certain parallel should be fixed upon as a limit of latitude, and a route laid down such that a great circle is followed as far as the limiting parallel, then the parallel itself, and finally another great circle to the port of destination. Such a modification of the great circle method is called *Composite Sailing*.

185. The *rhumb line* (art. 6, Chap. I), also called the *loxodromic curve*, which cuts all the meridians at the same angle, has been largely employed as a track by navigators on account of the ease with which it may be laid down on a Mercator chart. But as it is a longer line than the great circle between the same points, intelligent navigators of the present day use the latter wherever practicable. On the Mercator chart, however, the arc of a great circle joining two points (unless both are on the equator or both on the same meridian) will not be projected as a straight line, but as a curve which seems to be longer than the rhumb line; hence the shortest route appears as a circuitous one, and this is doubtless the reason that a wider use of the great circle has not been made.

It should be clearly understood that it is the rhumb line which is in fact the indirect route, and that in following the great circle the vessel is always heading for her port, exactly as if it were in sight, while on the course which is shown as a straight line on the Mercator chart the vessel never heads for her port until at the very end of the voyage.

186. The method of great circle sailing is of especial value to steamers, as such vessels need not, in the choice of a route, have regard for the winds to the same extent as must a sailing vessel; but even in navigating vessels under sail a knowledge of the great circle course may prove of great value. For example, suppose a ship to be bound from Sydney to Valparaiso; the first great circle course is SE. by S., while the Mercator course is almost due east. The distance is 748 miles shorter by the former route (if the great circle is followed throughout, though this would lead to a latitude of 61° S.). With the wind at E. ½ S. the ship would lie nearer to the Mercator course on the starboard tack, assuming that she sailed within six points of the wind; but if she took that tack she would be increasing her distance from the port of destination by 4½ miles in every 10 that she sailed; while on the port tack, heading one point farther from the rhumb, the gain toward the port would be 9½ miles out of every 10. Any course between East and SSW. would be better than the Mercator course; and if the wind were anything to the eastward of SE. by S., the ship would gain by taking the port tack in preference to the starboard.

187. As the great circle makes a different angle with each meridian that is crossed, it becomes necessary to make frequent changes of the ship's course; in practice, the course is a series of chords joining the various points on the track line.

If, while endeavoring to follow a great circle, the ship is driven from it, as by unfavorable weather, it will not serve the purpose to return to the old track at convenience, but it is required that another great circle be laid down, joining the actual position in which the ship finds herself with the port of destination.

188. The methods of determining the great circle course may be divided generally into four classes; namely, by *Great Circle Sailing Charts*, by *Computation*, by the methods of the *Time Azimuth*, and by *Graphic Approximations*.

189. Great Circle Sailing Charts.—Of the available methods, that by means of charts especially constructed for the purpose is considered greatly superior to all others.

A series of great circle sailing charts covering the navigable waters of the globe is published by the United States Hydrographic Office. Being on the gnomonic projection (art. 44, Chap. II), all great circles are represented as straight lines, and it is only necessary to join any two points by such a line to represent the great circle track between them. The courses and distance are readily obtainable by a method explained on the charts. The track may be transferred to a chart on the Mercator projection by plotting a number of its points by their coordinates and joining them with a curved line.

The navigator who contemplates the use of great circle tracks will find it of the greatest convenience to be provided with these gnomonic charts for the regions which his vessel is to traverse.

190. By Computation.—This method consists in determining a series of points on the great circle by their coordinates of latitude and longitude, plotting them upon a Mercator chart, and tracing the curve that joins them. The first point determined is the *vertex*, or point of highest latitude, even when, as sometimes occurs, it falls without that portion of the great circle which joins the points of departure and destination.

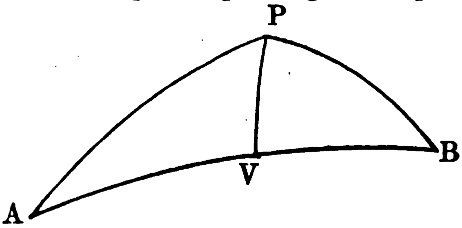

Fig. 28.

In figure 28, A represents the point of departure; B, the point of destination; AVB, the great circle joining them, with its vertex at V; and P, the pole of the earth.

Let C_A = PAB, the initial course;
C_B = PBA, the final course;
L_A, L_V, L_B = the latitudes of the respective points A, V, B = (90° − PA), (90° − PV), (90° − PB).
Lo_{AB}, Lo_{AV}, Lo_{BV} = the differences of longitude between A and B, A and V, B and V, respectively, = APB, APV, BPV.
D = the great circle distance between A and B; and
φ = an auxiliary angle introduced for the computation.

We then have:

$$\tan \varphi = \cos Lo_{AB} \cot L_B;$$
$$\cot C_A = \cot Lo_{AB} \cos (L_A + \varphi) \operatorname{cosec} \varphi;$$
$$\cot D = \cos C_A \tan (L_A + \varphi);$$
$$\cos L_V = \sin C_A \cos L_A;$$
$$\cot Lo_{AV} = \tan C_A \sin L_A.$$

By these formulæ are determined the initial course and the total distance by great circle; also the latitude of the vertex and its longitude with respect to A. By interchanging the subscript letters $_A$ and $_B$ throughout, we should obtain the final course, and the longitude of the vertex with respect to B; also the same total distance and latitude of the vertex as before.

In performing this computation, strict regard must be had to the signs of the quantities. If the points of departure and destination are in different latitudes, the latitude of one of these points must be regarded as negative with respect to the other, and they must be marked with opposite signs. Should Lo_{AV} or Lo_{BV} assume a negative value, it indicates that the vertex does not lie between A and B, and is to be laid off accordingly.

To find other points of the great circle, M, N, etc., let their latitudes be represented by L_M, L_N, etc., and their longitudes from the vertex by Lo_{VM}, Lo_{VN}, etc.; then

$$\tan L_M = \tan L_V \cos Lo_{VM}; \text{ or, } \cos Lo_{VM} = \tan L_M \cot L_V;$$
$$\tan L_N = \tan L_V \cos Lo_{VN}; \text{ or, } \cos Lo_{VN} = \tan L_N \cot L_V;$$

and so on. By these formulæ intervals of longitude from the vertex of 5°, 10°, or any amount, may be assumed, and the corresponding latitudes deduced; or any latitude may be assumed and its corresponding interval of longitude from the vertex found. Two positions will result from each solution, and the appropriate ones may be chosen by keeping in mind the signs involved.

Example: Given two places, one in Lat. 40° N., Long. 70° W., the other in Lat. 30° S., Long. 10° W., find the great circle distance between them; also the initial course, and the longitude of equator crossing.

$$L_A = +40°;\ L_B = -30°;\ Lo_{AB} = 60°.$$

Lo_{AB}	60°	cos	9.69897	..cot	9.76144						
L_B	− 30°	cot (−)	.23856								
L_A	+ 40°	....						cos	9.88425	sin	9.80807
φ	− 40° 54′	tan (−)	9.93753	..cosec (−)	.18393						
$(L_A+\varphi)$	− 0° 54′	................cos			9.99995	tan (−)	8.19616				
C_A	131° 24′ *or* S. 48° 36′ E....cot			(−)	9.94532	cos (−)	9.82041	sin	9.87513	tan (−)	.05472
D	89° 24′ *or* 5,364 miles........................					cot	8.01657				
L_V	+ 54° 56′	....						cos	9.75938		
Lo_{AV}	− 53° 54′	....								cot (−)	9.86279

44325°—18——6

The initial course is therefore S. 48° 36′ E., and the distance 5,364 nautical miles. (It may be found that the course by rhumb line is S. 38° 45′ E. and the distance 5,386 miles.) The vertex of the great circle is in Lat. 54° 56′ N., and is 53° 54′ in longitude from the point A, in a direction away from B; hence it is in Long. 123° 54′ W. To find the longitude of equator crossing let $L_M = 0°$; then in the equation,

$$\cos Lo_{VM} = \tan L_M \cot L_V,$$

since tan L_M equals zero, cos Lo_{VM} also equals zero, or the longitude interval from the vertex is 90°, which is evident from the properties of the great circle: therefore the longitude of equator crossing is 123° 54′ W.—90° = 33° 54′ W.

191. BY TIME AZIMUTH METHODS.—A convenient method of obtaining the initial and final courses in great circle sailing is afforded by the tables and graphic methods which are prepared for the solution of the *Time Azimuth* problem (art. 352, Chap. XIV). It will be found by comparison that if the latitude of the point of departure be substituted for the latitude of the observer in that problem, the latitude of destination for the declination of the celestial body, and the longitude interval for the hour angle, the solution for the initial course will coincide with that for the azimuth; by interchanging the latitudes of the points of departure and destination the final course will be similarly obtained. Advantage may thus be taken of the various methods provided for facilitating the determination of the azimuth to ascertain the great circle courses from one point to another.

192. BY GRAPHIC APPROXIMATIONS.—Of the numerous methods that fall within this class only two need be given.

193. By the use of a *Terrestrial Globe* the two given points between which the great circle track is required may be joined by the shortest line between them, either by means of a piece of thread or by moving the globe until they are brought to the fixed horizon which is usually provided; the coordinates of the various points of the track are then transferred to the chart. The number of minutes of arc, as measured on the scale of the horizon between the points, equals the number of miles of distance; if there be no horizon, the measure may be made by a thread along the equator or a meridian.

194. The *Method of Professor Airy* consists in drawing on the chart a rhumb line joining the two points, and erecting at its middle point a perpendicular; the following table should then be entered with the middle latitude as an argument, and the "corresponding parallel" of latitude taken out (noting whether it is the same or opposite in name to the middle latitude); where this parallel is intersected by the perpendicular that was drawn will be the center from which may be swept an arc approximately representing the great circle between the two points.

Middle latitude.	Corresponding parallel.	Name.	Middle latitude.	Corresponding parallel.	Name.
°	° ′		°	° ′	
20	81 13	Opposite.	52	11 33	Opposite.
22	78 16	Do.	54	6 24	Do.
24	74 59	Do.	56	1 13	Do.
26	71 26	Do.	58	4 00	Same.
28	67 38	Do.	60	9 15	Do.
30	63 37	Do.	62	14 32	Do.
32	59 25	Do.	64	19 50	Do.
34	55 05	Do.	66	25 09	Do.
36	50 36	Do.	68	30 30	Do.
38	46 00	Do.	70	35 52	Do.
40	41 18	Do.	72	41 14	Do.
42	36 31	Do.	74	46 37	Do.
44	31 38	Do.	76	52 01	Do.
46	26 42	Do.	78	57 25	Do.
48	21 42	Do.	80	62 51	Do.
50	16 39	Do.			

COMPOSITE SAILING.

195. It has already been stated that when, for any reason, it is impracticable or unadvisable to follow the great circle track to its highest latitude, a limiting parallel is chosen and the route modified accordingly. This method is denominated *Composite Sailing.*

196. The shortest track between points where a fixed latitude is not exceeded is made up as follows:

1. A great circle through the point of departure tangent to the limiting parallel.
2. A course along the parallel.
3. A great circle through the point of destination tangent to the limiting parallel.

The composite track may be determined by *Great Circle Sailing Chart*, by *Computation*, or by *Graphic Approximation.*

197. On a *Great Circle Sailing Chart*, draw lines from the points of departure and destination, respectively, tangent to the limiting parallel; transfer these great circles to a Mercator chart in the usual manner, by the coordinates of several points, including in each case the point of tangency to the parallel. Follow the first great circle to the parallel; then follow the parallel; then the second great circle. Determine great circle courses and distances from the gnomonic chart as thereon described; determine the distance along the parallel by Parallel Sailing.

198. *By computation*, the problem consists in finding the great circles which pass, respectively, through the points of departure and destination and have their vertices in the latitude of the limiting parallel. Resuming the designation of terms already employed (art. 190), we have:

$$\cos Lo_{VA} = \tan L_A \cot L_V;$$
$$\cos Lo_{VB} = \tan L_B \cot L_V;$$

where Lo_{VA} and Lo_{VB} represent the distances in longitude from A and from B to the respective points of tangency; other features of each of the great circles may be determined in the usual manner.

EXAMPLE: A vessel in Lat. 30° S., Long. 18° W., is bound to a point in Lat. 39° S., Long. 145° E., and it is decided not to go south of the parallel of 55° S. Find the longitude of reaching that parallel and the longitude at which it should be left.

$L_A = 30°$ S.; $L_B = 39°$ S.; $L_V = 55°$ S.
$Lo_A = 18°$ W.; $Lo_B = 145°$ E.

L_A	30°	tan 9.76144	L_B	39°		tan 9.90837
L_V	55°	cot 9.84523	L_V	55°		cot 9.84523
Lo_{VA}	66° 09′ E.	cos 9.60667	Lo_{VB}	55° 27′ W.	cos	9.75360
Lo_A	18 00 W.		Lo_B	145 00 E.		
Lo_V	48 09 E.		Lo_V	89 33 E.		

199. A *graphic approximation* to the composite track may be obtained by drawing a straight line between the given points on a Mercator chart and erecting at its middle point a perpendicular, which should be extended until it intersects the limiting parallel. Then through this intersection and the two points describe the arc of a circle, and this will approximate to the shortest distance within the assigned limit of latitude.

200. A terrestrial globe may be employed for the determination of the composite track; the method of its use will suggest itself.

201. Another approximation is obtained by joining the two points with a single great circle, and following this to its intersection with the limiting parallel; thence sailing along the parallel until the great circle is again intersected; then resuming the circle and following it to the destination.

CHAPTER VI.

DEAD RECKONING.

202. *Dead Reckoning* is the process by which the position of a ship at any instant is found by applying to the last well-determined position the run that has since been made, using for the purpose the ship's course and the distance indicated by the log.

203. Positions by dead reckoning, also spoken of as positions *by account*, differ from those determined by bearings of terrestrial objects or by observations of celestial bodies in being less exact, as the correctness of dead reckoning depends upon the accuracy of the estimate of the run, and this is always liable to be at fault to a greater or less extent. The course made good by a ship may differ from that which it is believed that she is making good, by reason of imperfect steering, improper allowance for compass error and leeway,* and the effects of unknown currents; the allowed distance over the ground may be in error on account of inaccurate logging and unknown currents.

Notwithstanding its recognized defects as compared with the more exact methods, the dead reckoning is an invaluable aid to the mariner. It affords him a means of plotting the position of the ship at any desired time between astronomical determinations; it also gives him an approximate position at the moment of taking astronomical observations which is a great convenience in working up those observations; and finally it affords the only available means of determining the location of a vessel at sea during those periods (which may continue for several days together) when the weather is such as to render the observation of celestial bodies an impossibility.

204. Taking Departure.—Before losing sight of the land, and preferably while objects remain in good view, it is the duty of the navigator to *take a departure;* this consists in fixing the position of the ship by the best means available (Chap. IV), and using this position as the origin for dead reckoning. There are two methods of reckoning the departure. The first and simpler consists in taking from the chart the latitude and longitude of the position found, and applying the future run thereto. The other requires that the bearing and distance of an object of known latitude and longitude be found; the position of the object then forms the basis of the reckoning, and the *reversed* direction of the bearing, with the distance, forms the first course and distance; thus it may be considered that the ship starts from the position of the object and sails to the position where the bearing was taken; the correction for deviation in such a case should be that due to the heading of the ship when the bearing was taken. Each time that a new position is determined it is used as a new departure for the dead reckoning.

This meaning of the term *departure* should not be confounded with the other, which refers to the distance run toward east or west.

205. Methods.—The working of dead reckoning merely involves an application of the methods of Traverse Sailing (art. 172) and Middle Latitude Sailing (art. 175), as explained in Chapter V.

The various compass courses are set down in a column, and abreast each are written the errors by reason of which the course steered by compass differs from the true course made good over the ground; thence the true course made good is determined and recorded; next, the distance is written in, and afterwards, by means of Tables 1 or 2 (according as the courses are expressed in quarter points or degrees), the difference of latitude and departure are found, separate columns being kept for distances to the north, south, east, and west.

When the position of the ship at any moment is required, add up all the differences of latitude and departure, and write in the column of the greater the difference between the northing and southing, and the easting and westing. Apply the difference of latitude to the latitude of the last determined position, which will give the

* The effect of the lateral movement of a vessel, produced by the pressure of the wind blowing across the direction of the heading upon which the vessel is being steered, in causing the track actually traversed to incline to leeward of the direction steered by an amount depending upon the force and direction of the wind and the characteristics of the vessel. In sailing vessels, in which the effect is greatest, the leeway may be readily estimated by observing the angle between the direction of the keel and the wake of the ship.

latitude by D. R., and from which may be found the middle latitude; with the middle latitude find the difference of longitude corresponding to the departure, apply this to the longitude of last position, and the result will be the longitude by D. R.

The employment of the tabular form will be found to facilitate the work and guard against errors. It will be a convenience to include in that form columns showing the hour, together with the reading of the patent log (if used) each time that the course is changed or the dead reckoning worked up.

The employment of minutes and tenths in dead reckoning rather than minutes and seconds is recommended.

EXAMPLE: A vessel under sail heading NE. ¾ E. (on which course deviation is ¼ pt. Easterly) takes departure from Cape Henry lighthouse (see Appendix IV for position), bearing SSW. ½ W. per compass, distant 1.4 miles. She then sails on a series of courses, with errors and distances as indicated below; wind about SE. by E. Required the position by dead reckoning; also the course and distance made good by dead reckoning.

Comp. course.	Var.	Dev.	Leeway.	Error.	True course.	Dist.	N.	S.	E.	W.	D. Lo.
NNE. ½ E.	½ W.	¼ E.		¼ W.	NNE. ¼ E.	1.4	1.3		0.6		
NE. ¾ E.	½ W.	¼ E.	¼ W.	½ W.	NE. ¼ E.	27.6	18.5		20.5		
S. by W.	½ W.,	0	¼ E.	¼ W.	S. ¾ W.	31.5		31.2		4.6	
ENE.	½ W.	¼ E.	½ W.	¾ W.	NE. by E. ¼ E.	14.2	7.3		12.2		
S. ½ E.	½ W.	0	½ E.	0	S. ½ E.	11.0		11.0	0.5		
NE. ¼ N.	½ W.	¼ E.	½ W.	¾ W.	NE. by N.	87.0	72.3		48.3		
							99.4	42.2	82.1	4.6	
Made good,					NE. ¾ E.	96.5	57.2		77.5		97.0

	Latitude.		*Longitude.*
Point of departure,	36° 55′.6 N.		76° 00′.5 W.
Run,	57.2 N.	Mid. L., 37°	1 37.0 E.
By D. R.	37 52.8 N.		74 23.5 W.

EXAMPLE: A steamer's position by observation at noon, patent log reading 27.3, is Lat. 49° 15′ N., Long. 7° 32′ W. Thence she steers 262° (per compass), the total compass error on that course being 20° W., until 12.30, at which time, patent log reading 33.9, the course is changed to 260° (*p. c.*), same error. At 4.12, patent log 80.5, sights are taken from which it is found that the true longitude is 8° 46′ W., and the compass error 19° W. At 6.15, patent log reading 6.1, a sight is taken from which it is found that the true latitude is 48° 34′ 30″ N. At 8 p. m. the patent log reads 27.5. Required the positions by D. R. at each sight and at 8 o'clock.

Time.	Comp. course.	Error.	True course.	Pat. Log.	Dist.	S.	W.	D. Lo.
Noon.				27.3				
12.30	262°	20° W.	242°	33.9	6.6	3.1	5.8	
4.12	260°	20° W.	240°	80.5	46.6	23.3	40.3	
						26.4	46.1	70.3
6.15	260°	19° W.	241°	6.1	25.6	12.4	22.4	34.1
8.00	260°	19° W.	241°	27.5	21.4	10.4	18.7	27.9

	Latitude.		*Longitude.*
By obs. at noon,	49° 15′.0 N.		7° 32′.0 W.
Run to 4.12 sight,	26.4 S.	Mid. L., 49°	1 10.3 W.
By D. R. at 4.12 sight,	48 48.6 N.		8 42.3 W.
By obs. at 4.12 sight,			8 46.0 W.
Run to 6.15 sight,	12.4 S.	Mid. L., 49°	34.1 W.
By D. R. at 6.15 sight,	48 36.2 N.		9 20.1 W.
By obs. at 6.15 sight,	48 34.5 N.		
Run to 8 p. m.,	10.4 S.	Mid. L., 48°	27.9 W.
By D. R. at 8 p. m.,	48 24.1 N.		9 48.0 W.

206. Allowance for Current.—When a vessel is sailing in a known current whose strength may be estimated with a fair degree of accuracy, a more correct position may be arrived at by regarding the set and drift of the current as a course and distance to be regularly taken account of in the dead reckoning.

Example: A vessel in the Gulf Stream at a point where the current is estimated to set 48° at the rate of 1.8 miles an hour, sails 183° (true), making 9.5 knots an hour through the water for $3^h\ 30^m$. Middle latitude 35°. Required the course and distance made good.

	True course.	Dist.	N.	S.	E.	W.	D. Lo.
Run	183°	33.3		33.3		1.7	
Current	48°	6.3	4.2		4.7		
Made good	174°	29.3		29.1	3.0		3.6

207. Finding the Current.—It is usual, upon obtaining a good position by observation (as the navigator usually does at noon), to compare that position with the one obtained by dead reckoning, and to attribute such discrepancy as may be found to the effects of current. It has already been pointed out that other causes than the motion of the water tend to make the dead reckoning inaccurate, so that it must not be assumed that currents proper are thus determined with complete correctness.

Current is said to have *set* and *drift*, referring respectively to the direction toward which it is flowing and the velocity with which it moves.

It is evident that, in calculating current by the method of comparing positions by observation with those by account, the navigator must limit himself to the periods during which the dead reckoning has been brought forward independently, without receiving any corrections due to new points of departure. In case it is desired to find the current covering a period during which fresh departures have been used, as from noon to noon, find the algebraical sums of all the differences of latitude and longitude from the table, and apply these to the latitude and longitude of original departure—that of the preceding noon; this gives the position from the ship's run proper, and the difference between this and the position by observation gives the set and drift for the twenty-four hours; if an allowance has been made for current, as explained in the preceding article, that must be omitted in bringing up the position which is to take account of the run only.

208. Day's Run.—It is usual to calculate, each day at noon, the ship's total run for the preceding twenty-four hours. Having the positions at noon of each day, the course and distance between them is found as explained in article 175, Chapter V. The position by observation is used in each case, if such has been found; otherwise, the position by dead reckoning.

Example: At noon, January 22, the position of a vessel by observation was Lat. 35° 10′ N., Long. 134° 01′ W. During the next 24 hours, the run by account was 60.1 miles north and 153.2 miles east. At noon, January 23, the position by observation was Lat. 36° 03′ N., Long. 131° 14′ W. Required the position by D. R. at the latter time; also the run and current for the 24 hours.

	Latitude.		*Longitude.*
By obs., noon, 22d,	35° 10′.0 N.	Mid. L., 36°	134° 01′.0 W.
Run,	1 00 .1 N.	Dep., 153.2 E.	3 09 .4 E.
		D.Lo., 189.4 E.	
By D. R., noon, 23d,	36 10 .1 N.		130 51 .6 W.
By obs., noon, 23d,	36 03 .0 N.	D.Lo., 22.4 W.	131 14 .0 W.
Current,	7 .1 S.	Dep., 18.1 W.	22.4 W.

Current for 24 hours, 7.1 S., 18.1 W.=249°, 19.4 miles.
Current per hour, 249°, 0.8 mile.

	Latitude.		*Longitude.*
By obs., noon, 23d,	36° 03′.0 N.	Mid. L., 36°	131° 14′.0 W.
By obs., noon, 22d,	35 10 .0 N.	D.Lo., 167.0E.	134 01.0 W.
Run,	0 53 .0 N.	Dep., 135.1	2 47 .0 E.

Run for 24 hours, 53.0 N., 135.1 E.=68°, 146 miles.

CHAPTER VII.

DEFINITIONS RELATING TO NAUTICAL ASTRONOMY.

209. *Nautical Astronomy*, or *Celo-Navigation*, has been defined (art. 3, Chap. I) as that branch of the science of Navigation in which the position of a ship is determined by the aid of celestial objects—the sun, moon, planets, or stars.

210. THE CELESTIAL SPHERE.—An observer upon the surface of the earth appears to view the heavenly bodies as if they were situated upon the surface of a vast hollow sphere, of which his eye is the center. In reality we know that this apparent vault has no existence, and that we can determine only the relative directions of the heavenly bodies—not their distances from each other or from the observer. But by adopting an imaginary spherical surface of an infinite radius, the eye of the observer being at the center, the places of the heavenly bodies can be projected upon this *Celestial Sphere*, or *Celestial Concave*, at points where the lines joining them with the center intersect the surface of the sphere. Since, however, the center of the earth should be the point from which all angular distances are measured, the observer, by transferring himself there, will find projected on the celestial sphere, not only the heavenly bodies, but the imaginary points and circles of the earth's surface. The actual position of the observer on the surface will be projected in a point called the *zenith;* the meridians, equator, and all other lines and points may also be projected.

211. An observer on the earth's surface is constantly changing his position with relation to the celestial bodies projected on the sphere, thus giving to the latter an apparent motion. This is due to three causes: First, the diurnal motion of the earth, arising from its rotation upon its axis; second, the annual motion of the earth, arising from its motion about the sun in its orbit; and third, the actual motion of certain of the celestial bodies themselves. The changes produced by the diurnal motion are different for observers at different points upon the earth, and therefore depend upon the latitude and longitude of the observer. But the changes arising from the other causes named are independent of the observer's position, and may therefore be considered at any instant in their relation to the center of the earth. To this end the elements necessary for any calculation are tabulated in the *Nautical Almanac* from data based upon laws which have been found by long series of observations to govern the actual and apparent motion of the various bodies.

212. The *Zenith* of an observer on the earth's surface is the point of the celestial sphere vertically overhead. The *Nadir* is the point vertically beneath.

213. The *Celestial Horizon* is the great circle of the celestial sphere formed by passing a plane through the center of the earth at right angles to the line which joins that point with the zenith of the observer. The celestial horizon differs somewhat from the *Visible Horizon*, which is that line appearing to an observer at sea to mark the intersection of earth and sky. This difference arises from two causes: First, the eye of the observer is always elevated above the sea level, thus permitting him a range of vision exceeding 90° from the zenith; and second, the observer's position is on the surface instead of at the center of the earth. These causes give rise, respectively, to *dip of the horizon* and *parallax*, which will be explained later (Chap. X).

214. In figure 29 the celestial sphere is considered to be projected upon the celestial horizon, represented by NESW.; the zenith of the observer is projected at Z, and that pole of the earth which is elevated above the horizon, assumed for illustration to be the north pole, appears at P, the *Elevated Pole* of the celestial sphere. The other pole is not shown in the figure.

215. The *Equinoctial*, or *Celestial Equator*, is the great circle formed by extending the plane of the earth's equator until it intersects the celestial sphere. It is shown in the figure in the line EQW. The equinoctial intersects the horizon in E and W, its east and west points.

216. *Hour Circles, Declination Circles*, or *Celestial Meridians* are great circles of the celestial sphere passing through the poles; they are therefore secondary to the equinoctial, and may be formed by extending the planes of the respective terrestrial meridians until they intersect the celestial sphere. In the figure, PB, PS, PB′, are hour circles, and that one, PS, which contains the zenith and is therefore formed by the extension of the terrestrial meridian of the observer, intersects the horizon in N and S, its north and south points.

217. *Vertical Circles*, or *Circles of Altitude*, are great circles of the celestial sphere which pass through the zenith and nadir; they are therefore secondary to the horizon. In the figure, ZH, WZE, NZS, are projections of such circles, which being at right angles to the plane of projection, appear as straight lines. The vertical circle NZS, which passes through the poles, coincides with the meridian of the observer. The vertical circle WZE, whose plane is at right angles to that of the meridian, intersects the horizon in its eastern and western points, and, therefore, at the points of intersection of the equinoctial; this circle is distinguished as the *Prime Vertical.*

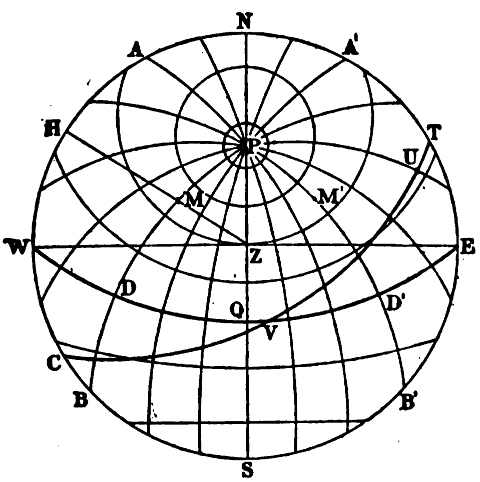

Fig. 20.

218. The *Declination* of any point in the celestial sphere is its angular distance from the equinoctial, measured upon the hour or declination circle which passes through that point; it is designated as *North* or *South* according to the direction of the point from the equinoctial; it is customary to regard north declinations as positive (+), and south declinations as negative (−). In the figure, DM is the declination of the point M. Declination upon the celestial sphere corresponds with latitude upon the earth.

219. The *Polar Distance* of any point is its angular distance from the pole (generally, the elevated pole of an observer), measured upon the hour or declination circle passing through the point; it must therefore equal 90° *minus* the declination, if measured from the pole of the same name as the declination, or 90° *plus* the declination, if measured from the pole of opposite name. The polar distance of the point M from the elevated pole P is PM.

220. The *Altitude* of any point in the celestial sphere is its angular distance from the horizon, measured upon the vertical circle passing through the point; it is regarded as positive when the body is on the same side of the horizon as the zenith. The altitude of the point M is HM.

221. The *Zenith Distance* of any point is its angular distance from the zenith, measured upon the vertical circle passing through the point; the zenith distance of any point which is above the horizon of an observer must therefore equal 90° *minus* the altitude. The zenith distance of M, in the figure, is ZM.

222. The *Hour Angle* of any point is the angle at the pole between the meridian of the observer and the hour circle passing through that point; it may also be regarded as the arc of the equinoctial intercepted between those circles. It is measured toward the west as a positive direction through the twenty-four hours, or 360 degrees, which constitute the interval between the successive returns to the meridian, due to the diurnal rotation of the earth, of any point in the celestial sphere. The hour angle of M is the angle QPD, or the arc QD.

223. The *Azimuth* of a point in the celestial sphere is the angle at the zenith between the meridian of the observer and the vertical circle passing through the point; it may also be regarded as the arc of the horizon intercepted between those circles. It is measured from either the north or the south point of the horizon (usually that one of the same name as the elevated pole) to the east or west through 180°, and is named accordingly; as, N. 60° W., or S. 120° W. The azimuth of M is the angle NZH, or the arc NH, from the north point, or the angle SZH, or the arc SH, from the south point of the horizon.

224. The *Amplitude* of a point is the angle at the zenith between the prime vertical and the vertical circle of the point; it is measured from the east or the west point of the horizon through 90°, as W. 30° N. It is closely allied with the azimuth and may always be deduced therefrom. In the figure, the amplitude of H is the angle WZH, or the arc WH. The amplitude is only used with reference to points in the horizon.

225. The *Ecliptic* is the great circle representing the path in which, by reason of the annual revolution of the earth, the sun appears to move in the celestial sphere; the plane of the ecliptic is inclined to that of the equinoctial at an angle of 23° 27½′, and this inclination is called the *obliquity of the ecliptic.* The ecliptic is represented by the great circle CVT.

226. The *Equinoxes* are those points at which the ecliptic and the equinoctial intersect, and when the sun occupies either of these positions the days and nights are of equal length throughout the earth. The *Vernal Equinox* is that one at which the sun appears to an observer on the earth when passing from southern to northern declination, and the *Autumnal Equinox* that one at which it appears when passing from northern to southern declination. The Vernal Equinox is also designated as the *First Point of Aries,* and is used as an origin for reckoning right ascension; it is indicated in the figure at V.

227. The *Solstitial Points,* or *Solstices,* are points of the ecliptic at a distance of 90° from the equinoxes, at which the sun attains its highest declination in each hemisphere. They are called respectively the *Summer* and the *Winter Solstice,* according to the season in which the sun appears to pass these points in its path. The Summer Solstice is indicated in the figure at U.

228. The *Right Ascension* of a point is the angle at the pole between the hour circle of the point and that of the First Point of Aries; it may also be regarded as the arc of the equinoctial intercepted between those circles. It is measured from the First Point of Aries to the eastward as a positive direction, through twenty-four hours or 360 degrees. The right ascension of the point M′ is VD′.

229. *Celestial Latitude* is measured to the north or south of the ecliptic upon great circles secondary thereto. *Celestial Longitude* is measured upon the ecliptic from the First Point of Aries as an origin, being regarded as positive to the eastward throughout 360°.

230. Coordinates.—In order to define the position of a point in space, a system of lines, angles, or planes, or a combination of these, is used to refer it to some fixed line or plane adopted as the primitive; and the lines, angles, or planes by which it is thus referred are called *coordinates.*

231. In figure 30 is shown a system of rectilinear coordinates for a plane. A fixed line FE is chosen, and in it a definite point C, as the *origin.* Then the position of a point A is defined by $CB = x$, the distance from the origin, C, to the foot of a perpendicular let fall from A on FE; and by $AB = y$, the length of the perpendicular. The distance x is called the *abscissa* and y the *ordinate.* Assuming two intersecting right lines FE and HI as standard lines of reference, the location of the point A is defined by its distance from each in a direction parallel to the other.

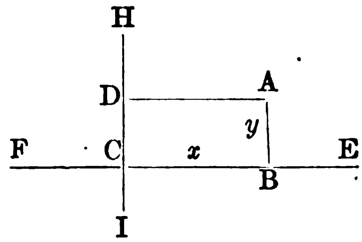

Fig. 30.

An exemplification of this system is found in the chart, on which FE is represented by the equator, HI by the prime meridian; the coordinates x and y being the longitude and latitude of the point A.

232. The great circle is to the sphere what the straight line is to the plane; hence, in order to define the position of a point on the surface of a sphere, some great circle must be selected as the primary, and some particular point of it as the origin. Thus, in figure 31, which represents the case of a sphere, some fixed great circle, CBQ, is selected as the axis and called the *primary;* and a point C is chosen as the origin. Then to define the position of any point A, the abscissa x equals the distance from C to the point B, where the secondary great circle through A intersects the primary; the ordinate y equals the distance of A from the primary measured on the secondary—that is, $x = CB$ and $y = AB$.

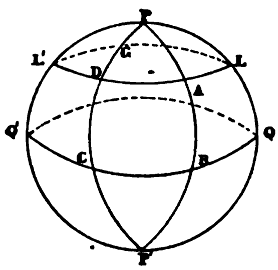
FIG. 31.

233. In the case of the earth, the primary selected is the equator (its plane being perpendicular to the earth's axis), and upon this are measured the abscissæ, while upon the secondaries to it are measured the ordinates of all points on the earth's surface. The initial point for reference on the equator is determined by the *prime meridian* chosen, West longitudes and North latitudes being called *positive,* East longitudes and South latitudes, *negative.*

234. In the case of the celestial sphere, there are four systems of coordinates in use for defining the position of any point; these vary according to the circle adopted as the primary and the point used as an origin. They are as follows:

1. Altitude and azimuth.
2. Declination and hour angle.
3. Declination and right ascension.
4. Celestial latitude and longitude.

235. In the system of *Altitude and Azimuth,* the primary circle is the celestial horizon, the secondaries to which are the vertical circles, or circles of altitude. The horizon is intersected by the celestial meridian in its northern and southern points, of which one—usually that adjacent to the elevated pole—is selected as an origin for reckoning coordinates. The azimuth indicates in which vertical circle the point to be defined is found, and the altitude gives the position of the point in that circle. In figure 29 the point M is located, according to this system, by its azimuth NH and altitude HM.

236. In the system of *Declination and Hour Angle,* the primary circle is the equinoctial, the secondaries to which are the circles of declination, or hour circles. The point of origin is that point of intersection of the equinoctial and celestial meridian which is above the horizon. The hour angle indicates in which declination circle the point to be defined is found, and the declination gives the position of the point in that circle. In figure 29 the point M is located, according to this system, by its hour angle QD and declination DM.

237. In the system of *Declination and Right Ascension,* the primary and secondaries are the same as in the system just described, but the point of origin differs, being assumed to be at the First Point of Aries, or vernal equinox. The right ascension indicates in which declination circle the point to be defined may be found, and the declination gives the position in that circle. In figure 29 the point M′ is located by VD′, the right ascension, and D′M′, the declination. It should be noted that this system differs from the preceding in that the position of a point is herein referred to a fixed point in the celestial sphere and is independent of the zenith of the observer as well as of the position of the earth in its diurnal motion, while, in the system of declination and hour angle, both of these are factors in determining the coordinates.

238. In the system of *Celestial Latitude and Longitude,* the primary circle is the ecliptic; the point of origin, the First Point of Aries. The method of reckoning by this system, which is of only slight importance in Nautical Astronomy, will appear from the definitions of celestial latitude and longitude already given (art. 229).

CHAPTER VIII.

INSTRUMENTS EMPLOYED IN NAUTICAL ASTRONOMY.

THE SEXTANT.

239. The *sextant* is an instrument for measuring the angle between two objects by bringing into coincidence at the eye of the observer rays of light received directly from the one and by reflection from the other, the measure being afforded by the inclination of the reflecting surfaces. By reason of its small dimensions, its accuracy, and, above all, the fact that it does not require a permanent or a stable mounting but is available for use under the conditions existing on shipboard, it is a most important instrument for the purposes of the navigator. While the sextant is not capable of the same degree of accuracy as fixed instruments, its measurements are sufficiently exact for navigation.

240. Description.—A usual form of the sextant is represented in figure 32. The frame is of brass or some similar alloy. The graduated arc, AA, generally of silver, is marked in appropriate divisions; in the finer sextants, each division represents 10′, and the vernier affords a means of reading to 10″. A wooden handle, H, is provided for holding the instrument. The *index mirror*, M, and *horizon mirror*, *m*, are of plate glass, and are silvered, though the upper half of the horizon glass is left plain to allow direct rays to pass through unobstructed. To give greater distinctness to the images, a small *telescope*, E, is placed in the line of sight; it is supported in a ring, K, which can be moved by a screw in a direction at right angles to the plane of the sextant, thus shifting the axis of the telescope, and therefore the plane of reflection; this plane, however, always remains parallel to that of the instrument, the motion of the telescope being intended merely to regulate the relative brightness of the direct and reflected image. In the ring, K, are small screws for the purpose of adjusting the telescope by making its axis parallel with the plane of the sextant. The vernier is carried on the end of an index bar pivoted beneath the index mirror, M, and thus travels along the graduated scale, affording a measure for any change of inclination of the index mirror; a reading glass, R, attached to the index bar and turning upon a pivot, S, facilitates the reading of vernier and scale. The index mirror, M, is attached to the head of the index bar, with its surface perpendicular to the plane of the instrument; an adjusting screw is fitted at the back to permit of adjustment to the perpendicular plane. The fixed glass *m*, half silvered and half plain, is called the *horizon glass*, as it is through this that the

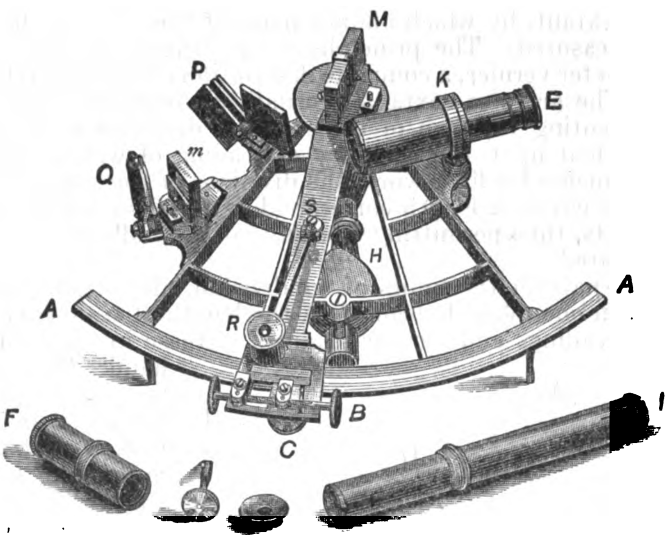

Fig. 32.

horizon is observed in measuring altitudes of celestial bodies; it is provided with screws, by which its perpendicularity to the plane of the instrument may be adjusted. At P and Q are colored glasses of different shades, which may be used separately or in combination to protect the eye from the intense light of the sun. In order to observe with accuracy and make the images come precisely in contact, a *tangent screw*, B, is fixed to the index, by means of which the latter may be moved with greater precision than by hand; but this screw does not act until the index is fixed by the screw C at the back of the sextant; when the index is to be moved any considerable amount, the screw C is loosened; when it is brought near to its required position the screw must be tightened, and the index may then be moved gradually by the tangent screw.

Besides the telescope, E, the instrument is usually provided with an inverting telescope, I, and a tube without glasses, F; also, with a cap carrying colored glasses, which may be put on the eye end of the telescope, thus dispensing with the necessity for the use of the colored shades, P and Q, and eliminating any possible errors which might arise from nonparallelism of their surfaces.

The latest type of sextant furnished to the United States Navy is fitted with an endless tangent screw which carries a micrometer drum from which the seconds of arc are read. By pressure of the thumb the tangent screw is released and the index bar may be moved to any position on the arc by hand, where the tangent screw is again thrown into gear by releasing the pressure of the thumb. The endless tangent screw is accomplished by cutting the edge of the arc with the worm teeth into which the tangent screw gears. At night the reading of this sextant is facilitated by a small electric light carried on it and supplied by a battery contained in the handle.

241. The *vernier* is an attachment for facilitating the exact reading of the scale of a sextant, by which aliquot parts of the smallest divisions of the graduated scale are measured. The principle of the sextant vernier is identical with that of the barometer vernier, a complete description of which will be found in article 52, Chapter II. The arc of a sextant is usually divided into 120 or more parts, each division representing 1°; each of these degree divisions is further subdivided to an extent dependent upon the accuracy of reading of which the sextant is capable. In the instruments for finer work, the divisions of the scale correspond to 10′ each, and the vernier covers a length corresponding to 59 such divisions, which is subdivided into 60 parts, thus permitting a reading of 10″; all sextants, however, are not so closely graduated.

Whatever the limits of subdivision, all sextants are fitted with verniers which contain one more division than the length of scale covered, and in which, therefore, scale-readings and vernier-readings increase in the same direction—toward the left hand. To read any sextant, it is merely necessary to observe the scale division next below, or to the right of, the zero of the vernier, and to add thereto the angle corresponding to that division of the vernier scale which is most nearly in exact coincidence with a division of the instrument scale.

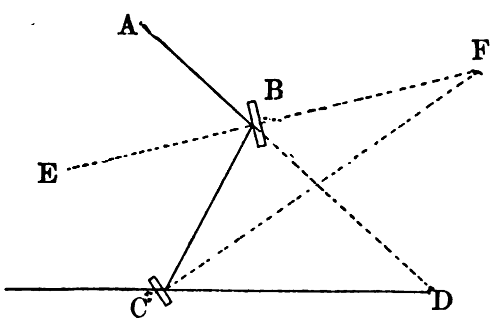

FIG. 33.

242. Optical Principle.—When a ray of light is reflected from a plane surface, the angle of incidence is equal to the angle of reflection. From this it may be proved that when a ray of light undergoes two reflections in the same plane the angle between its first and its last direction is equal to twice the inclination of the reflecting surfaces. Upon this fact the construction of the sextant is based:

In figure 33, let B and C represent respectively the index mirror and horizon mirror of a sextant; draw EF perpendicular to B, and CF perpendicular to C; then the angle CFB represents the inclination of the two mirrors. Suppose a ray to proceed from A and undergo reflection at B and at C, its last direction being CD; then ADC is the angle between its first and last directions, and we desire to prove that ADC = 2 CFB.

From the equality of the angles of incidence and reflection:

$$ABE = EBC, \text{ and } ABC = 2\ EBC;$$
$$BCF = FCD, \text{ and } BCD = 2\ BCF.$$

From Geometry:

$$ADC = ABC - BCD = 2\ (EBC - BCF) = 2\ CFB,$$

which is the relation that was to be proved.

243. In the sextant, since the index mirror is immovably attached to the index arm, which also carries the vernier, it follows that no change can occur in the inclination between the index mirror and the horizon mirror, excepting such as is registered by the travel of the vernier upon the scale.

If, when the index mirror is so placed that it is nearly parallel with the horizon mirror, an observer direct the telescope toward some well-defined object, there will be seen in the field of view two separate images of the object; and if the inclination of the index mirror be slightly changed by moving the index bar, it will be seen that while one of the images remains fixed the other moves. The fixed image is the direct one seen through the unsilvered part of the horizon glass, while the movable image is due to rays reflected by the index and horizon mirrors. When the two images coincide these mirrors must be parallel (assuming that the object is sufficiently distant to disregard the space which separates the mirrors; in this position of the index mirror the vernier indicates the true zero of the scale. If, however, instead of observing a single object, the instrument is so placed that the direct ray from one object appears in coincidence with the reflected ray of a second object, then the true angle between the objects will be twice the angle of inclination between the mirrors, or twice the angle measured by the vernier from the true zero of the scale. To avoid the necessity of doubling the angle on the scale, the latter is so marked that each half degree appears as a whole degree, whence its indications give the whole angle directly.

244. ADJUSTMENTS OF THE SEXTANT.—The theory of the sextant requires that, for accurate indications, the following conditions be fulfilled:

(*a*) The two surfaces of each mirror and shade glass must be parallel planes.

(*b*) The graduated arc or limb must be a plane, and its graduations, as well as those of the vernier, must be exact.

(*c*) The axis must be at the center of the limb, and perpendicular to the plane thereof.

(*d*) The index and horizon glasses must be perpendicular, and the line of sight parallel to the plane of the limb.

Of these, only the last named ordinarily require the attention of the navigator who is to make use of the sextant; the others, which may be called the *permanent adjustments*, should be made before the instrument leaves the hands of the maker, and with careful use will never be deranged.

245. The *Adjustment of the Index Mirror* consists in making the reflecting surface of this mirror truly perpendicular to the plane of the sextant. In order to test this, set the index near the middle of the arc, then, placing the eye very nearly in the plane of the sextant and close to the index mirror, observe whether the direct image of the arc and its image reflected from the mirror appear to form one continuous arc; if so, the glass is perpendicular to the plane of the sextant; if the reflected image appears to droop from the arc seen directly, the glass leans backward; if it seems to rise, the glass leans forward. The adjustment is made by the screws at the back of the mirror.

246. The *Adjustment of the Horizon Mirror* consists in making the reflecting surface of this mirror perpendicular to the plane of the sextant. The index mirror having been adjusted, if, in revolving it by means of the index arm, there is found one position in which it is parallel to the horizon glass, then the latter must also be perpendicular to the plane of the sextant. In order to test this, put in the telescope and direct it toward a star; move the index until the reflected image appears to pass the direct image; if one passes directly over the other the mirrors must be parallel·

if one passes on either side of the other the horizon glass needs adjustment, which is accomplished by means of the screws attached.

The sea horizon may also be used for making this adjustment. Hold the sextant vertically and bring the direct and the reflected images of the horizon line into coincidence; then incline the sextant until its plane makes but a small angle with the horizon; if the images still coincide the glasses are parallel; if not, the horizon glass needs adjustment.

247. The *Adjustment of the Telescope* must be so made that, in measuring angular distances, the line of sight, or axis of the telescope, shall be parallel to the plane of the instrument, as a deviation in that respect, in measuring large angles, will occasion a considerable error. To avoid such error, a telescope is employed in which are placed two wires, parallel to each other and equidistant from the center of the telescope; by means of these wires the adjustment may be made. Screw on the telescope, and turn the tube containing the eyeglass till the wires are parallel to the plane of the instrument; then select two clearly defined objects whose angular distance must be not less than 90°, because an error is more easily discovered when the angle is great; bring the reflected image of one object into exact coincidence with the direct image of the other at the inner wire; then, by altering slightly the position of the instrument, make the objects appear on the other wire; if the contact still remains perfect, the axis of the telescope is in its right situation; but if the two objects appear to separate or lap over at the outer wire the telescope is not parallel, and it must be rectified by turning one of the two screws of the ring into which the telescope is screwed, having previously unturned the other screw; by repeating this operation a few times the contact will be precisely the same at both wires, and the axis of the telescope will be parallel to the plane of the instrument.

Another method of making this adjustment is to place the sextant upon a table in a horizontal position, look along the plane of the limb, and make a mark upon a wall, or other vertical surface, at a distance of about 20 feet; draw another mark above the first at a distance equal to the height of the axis of the telescope above the plane of the limb; then so adjust the telescope that the upper mark, as viewed through the telescope, falls midway between the wires. Some sextants are accompanied by small sights whose height is exactly equal to the distance between the telescope and the plane of the limb; by the use of these, the necessity for employing the second mark is avoided and the adjustment can be very accurately made.

248. The errors which arise from defects in what have been denominated the *permanent adjustments* of the sextant may be divided into three classes, namely: Errors due to faulty centering of the axis, called *eccentricity;* errors of graduation; and errors arising from lack of parallelism of surfaces in index mirror and in shade glasses.

The errors due to eccentricity and faulty graduation are constant for the same angle, and should be determined once for all at some place where proper facilities for doing the work are at hand; these errors can only be ascertained by measuring known angles with the sextant. If angles of 10°, 20°, 30°, 40°, etc., are first laid off with a theodolite or similar instrument and then measured by the sextant, a table of errors of the sextant due to eccentricity and faulty graduation may be made, and the error at any intermediate angle found by interpolation; this table will include the error of graduation of the theodolite and also the error due to inaccurate reading of the sextant, but such errors are small. Another method for determining the combined errors of eccentricity and graduation is by measuring the angular distance between stars and comparing the observed and the computed arc between them, but this process is liable to inaccuracies by reason of the uncertainty of allowances for atmospheric refraction.

Errors of graduation, when large, may be detected by "stepping off" distances on the graduated arc with the vernier; place the zero of the vernier in exact coincidence with a division of the arc, and observe whether the final division of the vernier also coincides with a division of the arc; this should be tried at numerous positions of the graduated limb, and the agreement ought to be perfect in every case.

The error due to a prismatic index mirror may be found by measuring a certain unchangeable angle, then taking out the glass and turning the upper edge down, and measuring the angle again; half the difference of these two measures will be the error at that angle due to the mirror. From a number of measures of angles in this manner, a table similar to the one for eccentricity and faulty graduation can be made; or the two tables may be combined. When possible to avoid it, however, no sextant should be used in which there is an index mirror which produces a greater error than that due to the probable error of reading the scale. Mirrors having a greater angle than 2″ between their faces are rejected for use in the United States Navy. Index mirrors may be roughly tested by noting if there is an elongated image of a well-defined point at large angles.

Since the error due to a prismatic horizon mirror is included in the index correction (art. 249), and consequently applied alike to all angles, it may be neglected.

Errors due to prismatic shade glasses can be determined by measuring angles with and without the shade glasses and noting the difference. They may also be determined, where the glasses are so arranged that they can be turned through an angle of 180°, by measuring the angle first with the glass in its usual position and then reversed, and taking the mean of the two as the true measure.

249. INDEX ERROR.—The *Index Error* of a sextant is the error of its indications due to the fact that when the index and horizon mirrors are parallel the zero of the vernier does not coincide with the zero of the scale. Having made the adjustments of the index and horizon mirrors and of the telescope, as previously described, it is necessary to find that point of the arc at which the zero of the vernier falls when the two mirrors are parallel, for all angles measured by the sextant are reckoned from that point. If this point is to the left of the zero of the limb, all readings will be too great; if to the right of the zero, all readings will be too small.

If desirable that the reading should be zero when the mirrors are parallel, place the zero of the vernier on zero of the arc; then, by means of the adjusting screws of the horizon glass, move that glass until the direct and reflected images of the same object coincide, after which the perpendicularity of the horizon glass should again be verified, as it may have been deranged by the operation. This adjustment is not essential, since the correction may readily be determined and applied to the reading. In certain sextant work, however, such as surveying, it will be very convenient to be relieved of the necessity of correcting each angle observed. The sextant should never be relied upon for maintaining a constant index correction, and the error should be ascertained frequently. It is a good practice to verify the correction each time a sight is taken.

250. The *Index Correction* may be found (*a*) by a star, (*b*) by the sea horizon, and (*c*) by the sun.

(*a*) Bring the direct and reflected images of a star into coincidence, and read off the arc. The index correction is numerically equal to this reading, and is positive or negative according as the reading is on the right or left of the zero.

(*b*) The same method may be employed, substituting for a star the sea horizon, though this will be found somewhat less accurate.

(*c*) Measure the apparent diameter of the sun by first bringing the upper limb of the reflected image to touch the lower limb of the direct image, and then bringing the lower limb of the reflected image to touch the upper limb of the direct image.

Denote the readings in the two cases by r and r'; then, if S = apparent diameter of the sun, and R = the reading of the sextant when the two images are in coincidence, we have:

$$r = R + S,$$
$$r' = R - S,$$
$$R = \tfrac{1}{2}(r + r').$$

As R represents the *error*, the *correction* will be $-R$. Hence the rule: Mark the readings when *on* the arc with the *negative* sign; when *off*, with the *positive* sign; then the index correction is one-half the algebraic sum of the two readings.

EXAMPLE: The sun's diameter is measured for index correction as follows: On the arc, 31′ 20″; off the arc, 33′ 10″. Required the correction.

On the arc,	−31′	20″
Off the arc,	+33	10
2)	+ 1	50
I. C.,	+ 0	55

251. From the equations previously given, it is seen that:

$$S=\frac{1}{2}(r-r');$$

hence, if the observations are correct, it will be found that the sun's semidiameter, as given in the Nautical Almanac for the day of observation, is equal to one-fourth the algebraic difference of the readings. If required to obtain the index correction with great precision, several observations should be taken and the mean used, the accuracy being verified by comparing the tabulated with the observed semidiameter. If the sun is low, the horizontal semidiameter should be observed, to prevent the error that may arise from unequal refraction.

252. USE OF THE SEXTANT.—To measure the angle between any two visible objects, point the telescope toward the lower one, if one is above the other, or toward the left-hand one, if they are in nearly the same horizontal plane. Keep this object in direct view through the unsilvered part of the horizon glass, and move the index arm until the image of the other object is seen by a double reflection from the index mirror and the silvered portion of the horizon glass. Having gotten the direct image of one object into nearly exact contact with the reflected image of the other, clamp the index arm and, by means of the tangent screw, complete the adjustment so that the contact may be perfect; then read the limb.

In measuring the altitude of a celestial body above the sea horizon, it is necessary that the angle shall be measured to that point of the horizon which lies vertically beneath the object. To determine this point, the observer should move the instrument slightly to the right and left of the vertical, swinging it about the line of sight as an axis, taking care to keep the object in the middle of the field of view. The object will appear to describe the arc of a circle, and the lowest point of this arc marks the true vertical.

The shade glasses should be employed as may be necessary to protect the eye when observing objects of dazzling brightness, such as the sun, or the horizon when the sun is reflected from it at a low altitude. Care must be taken that the images are not too bright or the eye will be so affected as to interfere with the accuracy of the observations.

253. CHOICE OF SEXTANTS.—The choice of a sextant should be governed by the kind of work which is required to be done. In rough work, such as surveying, where angles need only be measured to the nearest 30″ the radius may be as small as 6 inches, which will permit easy reading, and the instrument can be correspondingly lightened. Where readings to 10″ are desired, as in nice astronomical work, the radius should be about 7½ inches, and the instrument, to be strongly built, should weigh about 3½ pounds.

The parts of an instrument should move freely, without binding or gritting. The eyepieces should move easily in the telescope tubes; the bracket for carrying the telescope should be made very strong. It is frequently found that the parallelism of the line of sight is destroyed in focusing the eyepiece, either on account of the looseness of the fit or because of the telescope bracket being weak. The vernier should lie close to the limbs to prevent parallax in reading. If it is either too loose or too tight at either extremity of its travel, it may indicate that the pivot is not perpendicular. The balls of the tangent screw should fit snugly in their sockets, so that there may be no lost motion.

Where possible, the sextant should always be submitted to expert examination and test as to the accuracy of its permanent adjustments before acceptance by the navigator.

254. RESILVERING MIRRORS.—Occasion may sometimes arise for resilvering the mirrors of a sextant, as they are always liable to be damaged by dampness or other causes. For this purpose some clean tin foil and mercury are required. Upon a piece of glass about 4 inches square lay a piece of tin foil whose dimensions exceed by about a quarter of an inch in each direction those of the glass to be silvered; smooth out the foil carefully by rubbing; put a small drop of mercury on the foil and spread it with the finger over the entire surface, being careful that none shall find its way under the foil; then put on a few more drops of mercury until the whole surface is fluid. The glass which is to be silvered having been carefully cleaned, it should be laid upon a piece of tissue paper whose edge just covers the edge of the foil and transferred carefully from the paper to the tin foil, a gentle pressure being kept upon the glass to avoid the formation of bubbles; finally, place the mirror face downward and leave it in an inclined position to allow the surplus mercury to flow off, the latter operation being hastened by a strip of tin foil at its lower edge. After five or six hours the tin foil around the edges may be removed, and the next day a coat of varnish made from spirits of wine and red sealing wax should be applied. For a horizon mirror care must be taken to avoid silvering the plain half. The mercury drawn from the foil should not be placed with clean mercury with a view to use in the artificial horizon or the whole will be spoiled.

255. OCTANTS AND QUINTANTS.—Properly speaking, a sextant is an instrument whose arc covers one-sixth of a complete circle, and which is therefore capable of measuring an angle of 120°. Other instruments are made which are identical in principle with the sextant as heretofore described, and which differ from that instrument only in the length of the arc. These are the *octant*, an eighth of a circle, by which angles may be measured to 90°, and the *quintant*, a fifth of a circle, which measures angles up to 144°. The distinction between these instruments is not always carefully made, and in such matters as have been touched upon in the foregoing articles the sextant may be regarded as the type of all kindred reflecting instruments.

THE ARTIFICIAL HORIZON.

256. The *Artificial Horizon* is a small, rectangular, shallow basin of mercury, over which, to protect the mercury from agitation by the wind, is placed a roof consisting of two plates of glass at right angles to each other. The mercury affords a perfectly horizontal surface which is at the same time an excellent mirror. The different parts of an artificial horizon are furnished in a compact form, a metal bottle being provided for containing the mercury when not in use, together with a suitable funnel for pouring.

If MN, in figure 34, is the horizontal surface of the mercury; S′B a ray of light from a celestial object, incident to the surface at B; BA the reflected ray; then an observer at A will receive the ray BA as if it proceeded from a point S″, whose angular depression, MBS″, below the horizontal plane is equal to the altitude, MBS′, of the object above that plane. If, then, SA is a direct ray from the object parallel to S′B, an observer at A can measure with the sextant the angle SAS″ = S′BS″ = 2 S′BM, by bringing the image of the object reflected by the index mirror into coincidence with the image S″ reflected by the mercury and seen through the horizon glass. The instrumental measure, corrected for index error, will be double the apparent altitude of the body.

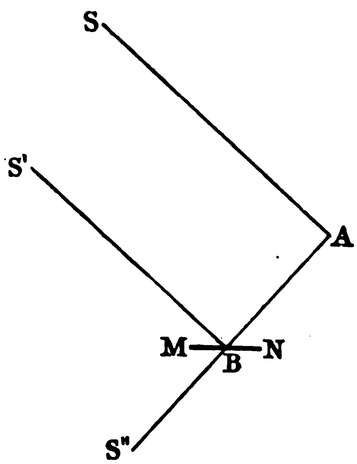

FIG. 34.

The sun's altitude will be measured by bringing the lower limb of one image to touch the upper limb of the other. Half the corrected instrumental reading will be the apparent altitude of the sun's *lower* or *upper* limb, according as the lower or upper limb of the *reflected* image was the one employed in the observation.

In observations of the sun with the artificial horizon, the eye is protected by a single dark glass over the eyepiece of the telescope through which direct and reflected rays must pass alike, thereby avoiding the errors that might possibly arise from a difference in the separate shade glasses attached to the frame of the sextant.

The glasses in the roof over the mercury should be made of plate glass, with perfectly parallel faces. If they are at all prismatic, the observed altitude will be erroneous. The error may be removed by observing a second altitude with the roof reversed, and, in general, by taking one-half of a set of observations with the roof in one position and the other half with the roof reversed. On the rare occasions when the atmosphere is so calm that the unsheltered mercury will remain undisturbed, most satisfactory observations may be made by leaving off the roof.

257. In setting up an artificial horizon, care should be taken that the basin is free from dust and other foreign matter, as small particles floating upon the surface of the mercury interfere with a perfect reflection. The basin should be so placed that its longer edge lies in the direction in which the observed body will bear at the middle of the observations. The spot selected for taking the sights should be as free as possible from causes which will produce vibration of the mercury, and precautions should be taken to shelter the horizon from the wind, as the mere placing of the roof will not ordinarily be sufficient to accomplish this. Embedding the roof in earth serves to keep out the wind, while setting the whole horizon upon a thick towel or a piece of such material as heavy felt usually affords ample protection from wind, tends to reduce the vibrations from mechanical shocks, and also aids in keeping out the moisture from the ground. In damp climates the roof should be kept dry by wiping, or the moisture deposited from the inclosed air will form a cloud upon the glass.

Molasses, oil, or other viscous fluid may, when necessary, be employed as a substitute for mercury.

258. Owing to the perfection of manufacture that is required to insure accuracy of results with the artificial horizon, navigators are advised to accept only such instrument as has satisfactorily stood the necessary tests to prove the correctness of its adjustment as regards the glasses of the roof.

THE CHRONOMETER.

259. The *Chronometer* is simply a correct time measurer, differing from an ordinary watch in having the force of its mainspring rendered uniform by means of a variable lever. Owing to the fact that on a sea voyage a chronometer is exposed to many changes of temperature, it is furnished with an expansion balance, formed of a combination of metals of different expansive qualities, which produces the required compensation. In order that its working may not be deranged by the motion of the ship in a seaway, the instrument is carried in gimbals.

As the regularity of the chronometer is essential for the correct determination of a ship's position, it is of the greatest importance that every precaution be taken to insure the accuracy of its indications. There is no more certain way of doing this than to provide a vessel with several of these instruments—preferably not less than three—in order that if an irregularity develop in one, the fact may be revealed by the others.

260. CARE OF CHRONOMETERS ON SHIPBOARD.—The box in which the chronometers are kept should have a permanent place as near as practicable to the center of motion of the ship, and where it will be free from excessive shocks and jars, such as those that arise from the engines or from the firing of heavy guns; the location should be one free from sudden and extreme changes of temperature, and as far removed as possible from masses of vertical iron. The box should contain a separate compartment for each chronometer, and each compartment should be lined with baize cloth padded with curled hair, for the double purpose of reducing shocks and equalizing the temperature within. An outer cover of baize cloth should be provided for the box, and this should be changed or dried out frequently in damp weather. The chronometers should all be placed with the XII mark in the same position.

For transportation for short distances by hand, an instrument should be rigidly clamped in its gimbals, for if left free to swing, its performance may be deranged by the violent oscillations that are imparted to it.

For transportation for a considerable distance, as by express, the chronometer should be allowed to run down, and should then be dismounted and the balance corked.

261. Since it is not possible to make a perfect instrument which will be uninfluenced by the disturbing causes incident to a sea voyage, it becomes the duty of the navigator to determine the *error* and to keep watch upon the variable *rate* of the chronometer.

The *error of the chronometer* is the difference between the time indicated and the standard time to which it is referred—usually Greenwich mean time.

The amount the chronometer *gains* or *loses* daily is the *daily rate*.

The indications of a chronometer at any given instant require a correction for the accumulated error to that instant; and this can be found if the error at any given time, together with the daily rate, are known.

262. WINDING.—Chronometers are ordinarily constructed to run for 56 hours without rewinding, and an indicator on the face always shows how many hours have elapsed since the last winding. To insure a uniform rate, they must be wound regularly every day, and, in order to avoid the serious consequences of their running down, the navigator should take some means to guard against neglecting this duty through a fault of memory. To wind, turn the chronometer gently on its side, enter the key in its hole and push it home, steadying the instrument with the hand, and wind to the left, the last half turn being made so as to bring up gently against the stop. After winding, cover the keyhole and return the instrument to its natural position. Chronometers should always be wound in the same order to prevent omissions, and the precaution taken to inspect the indicators, as a further assurance of the proper performance of the operation.

After winding each day, the comparisons should be made, and, with the readings of the maximum-and-minimum thermometer and other necessary data, recorded in a book kept for the purpose.

The maximum-and-minimum thermometer is one so arranged that its highest and lowest readings are marked by small steel indices that remain in place until reset. Every chronometer box should be provided with such an instrument, as a knowledge of the temperature to which chronometers have been subjected is essential in any analysis of the rate. To draw down the indices for the purpose of resetting, a magnet is used. This magnet should be kept at all times at a distance from the chronometers.

263. COMPARISON OF CHRONOMETERS.—The instrument believed to be the best is regarded as the *Standard*, and each other is compared with it. It is usual to designate the Standard as A, and the others as B, C, etc. Chronometers are made to beat half seconds, and any two may be compared by following the beat of one with the ear and of the other with the eye.

To make a comparison, say of A and B, open the boxes of these two instruments and close all others. Get the cadence and, commencing when A has just completed the beat of some even 5-second division of the dial, count "half-one-half-two-half-three-half-four-half-five," glancing at B in time to note the position of its second hand at the last count; the seconds indicated by A will be five greater than the number at the beginning of the count. The hours and minutes are also recorded for each chronometer, and the subtraction made. A good check upon the accuracy is afforded by repeating the operation, taking the tick from B.

Where necessary for exact work, it is possible to estimate the fraction between beats, and thus make the comparison to tenths of a second; but the nearest half second is sufficiently exact for the purposes of ordinary navigation at sea.

264. The following form represents a convenient method of recording comparisons:

STAND. A, No. 777. CHRO. B, No. 1509. CHRO. C, No. 1802.

Date, 1903.	Designation of comparisons.	Chro. B with Stand. A.	2d diff.	Chro. C with Stand. A.	2d diff.	Therm.			Bar.	Remarks.
						Max.	Min.	Air.		
		h. m. s.	s.	h. m. s.	s.	°	°	°	"	
January 1	Stand. A. B and C.	1 13 40 1 12 21.5		1 14 20 2 04 11		63	59	60	30.07	Found errors by time-ball.
	Difference.	1 18.5	—	11 10 09	—					
2	Stand. A. B and C.	1 16 30 1 15 10		1 17 00 2 06 51.5		64	58	57	30.12	Left New York for San Juan, P. R.
	Difference.	1 20	+1.5	11 10 08.5	−0.5					

265. The *second difference* in the form is the difference between the comparisons of the same instruments for two successive days. When a vessel is equipped with only one chronometer there is nothing to indicate any irregularity that it may develop at sea—and even the best instruments may undergo changes from no apparent cause. When there are two chronometers, the second difference, which is equal to the algebraic difference between their daily rates, remains uniform as long as the rates remain uniform, but changes if one of the rates undergoes a change; in such a case, there is no means of knowing which chronometer has departed from its expected performance, and the navigator must proceed with caution, giving due faith to the indications of each. If, however, there are three chronometers, an irregularity on the part of one is at once located by a comparison of the second differences. Thus, if the predicted rates of the chronometers were such as to give for the second difference of A − B, + $1^s.5$, and of A − C, − $0^s.5$, suppose on a certain day those differences were + $4^s.5$ and − $0^s.5$, respectively; it would at once be suspected that the irregularity was in B, and that that chronometer had lost 3^s on its normal rate during the preceding day. Suppose, however, the second differences were + $4^s.5$ and + $2^s.5$; it would then be apparent that A had gained 3^s.

266. TEMPERATURE CURVES.—Notwithstanding the care taken to eliminate the effect of a change of temperature upon the rate of a chronometer, it is rare that an absolutely perfect compensation is attained, and it may therefore be assumed that the rates of all chronometers vary somewhat with the temperature. Where the voyage of a vessel is a long one and marked changes of climate are encountered; the accumulated error from the use of an incorrect rate may be very material, amounting to several minutes' difference of longitude. Careful navigators will therefore take every means to guard against such an error. By the employment of a *temperature curve* in connection with the chronometer rate the most satisfactory results are arrived at.

267. There should be furnished with each chronometer a statement showing its daily rate under various conditions of temperature; and this may be supplemented by the observations of the navigator during the time that the chronometer remains on board ship. With all available data a temperature curve should be constructed which will indicate graphically the performance of the instrument. It is most convenient to employ for this purpose a piece of "profile paper," on which parallel lines are ruled at equal intervals at right angles to each other. Let each horizontal line represent, say, a degree of temperature, numbered at the left edge, from the bottom up; draw a vertical line in red ink to represent the zero rate, and let all rates to the right be *plus*, or gaining, and those to the left *minus*, or losing; let the intervals between vertical lines represent intervals of rate (as one-tenth of a second) numbered at the top from the zero rate; then on this scale plot the rate corresponding to each temperature; when there are several observations covering one height of the thermometer, the mean may be used. Through all the plotted points draw a fair curve, and the intersection of this curve with each temperature line gives the mean rate at that temperatnre. The mean temperature given by the maximum and minimum thermometer shows the rate to be used on any day.

268. HACK OR COMPARING WATCH.—In order to avoid derangement, the chronometers should never be removed from the permanent box in which they are kept on shipboard. When it is desired to mark a certain instant of time, as for an astronomical observation or for obtaining the chronometer error by signal, the time is marked by a "hack" (an inferior chronometer used for this purpose only), or by a comparing watch. Careful comparisons are taken—preferably both before and afterwards—and the chronometer time at the required instant is thus deduced. The correction represented by the chronometer time *minus* the watch time (twelve hours being added to the former when necessary to make the subtraction possible) is referred to as C − W.

Suppose, for example, the chronometer and watch are compared and their indications are as follows:

Chro. t.,	5^h	27^m	30^s
W. T.,	−2	36	45.5
C − W,	2	50	44.5

If then a sight is taken when the watch shows $3^h\ 01^m\ 27^s.5$, we have:

W. T.,	3^h	01^m	$27^s.5$
C−W,	+2	50	44.5
Chro. t.,	5	52	12.0

It may occur that the values of C−W, as obtained from comparisons before and after marking the desired time, will vary; in that case the value to be used will be the mean of the two, if the time marked is about midway between comparisons, but if much nearer to one comparison than the other, allowance should be made accordingly.

Thus suppose, in the case previously given, a second comparison had been taken after the sight as follows:

Chro. t.,	6^h	12^m	45^s
W. T.,	−3	21	59.5
C−W,	2	50	45.5

The sight having been taken at about the middle of the interval, the C−W to be used would be the mean of the two, or $2^h\ 50^m\ 45^s.0$.

Let us assume, however, that the second comparison showed the following:

Chro. t.,	6^h	38^m	25^s
W. T.,	−3	47	39
C−W,	2	50	46

Then, the sight having been taken when only about one-third of the interval had elapsed between the first and second comparisons, it would be assumed that only one-third of the total change in the C−W had occurred up to the time of sight, and the value to be used would be $2^h\ 50^m\ 45^s.0$.

269. It is considered a good practice always to subtract watch time from chronometer time, whatever the relative values, and thus to employ C−W invariably as an additive correction. It is equally correct to take the other difference, W−C, and make it subtractive; it may sometimes occur that a few figures will thus be saved, but a chance for error arises from the possibility of inadvertently using the wrong sign, which is almost impossible by the other method. Thus, the following example may be taken:

Comparison	C,	10^h	57^m	38^s	W,	11^h	42^m	35^s
	W,	−11	42	35	C,	−10	57	38
	C−W,	11	15	03	W−C,	0	44	57
Sight	W,	11	50	21	W,	11	50	21
	C−W,	+11	15	03	W−C,	−0	44	57
	C,	11	05	24	C,	11	05	24

CHAPTER IX.

TIME AND THE NAUTICAL ALMANAC.

270. The subjects of *Time* and the *Nautical Almanac* are two of the most important ones to be mastered in the study of Nautical Astronomy, as they enter into every operation for the astronomical determination of a ship's position. They will be treated in conjunction, as the two are interdependent.

METHODS OF RECKONING TIME.

271. The instant at which any point of the celestial sphere is on the meridian of an observer is termed the *transit, culmination,* or *meridian passage* of that point; when on that half of the meridian which contains the zenith, it is designated as *superior* or *upper* transit; when on the half containing the nadir, as *inferior* or *lower* transit.

272. Three different kinds of time are employed in astronomy—(*a*) *apparent* or *solar time,* (*b*) *mean time,* and (*c*) *sidereal time.* These depend upon the hour angle from the meridian of the points to which they respectively refer. The point of reference for apparent or solar time is the *Center of the Sun;* for mean time, an imaginary point called the *Mean Sun;* and for sidereal time, the *Vernal Equinox,* also called the *First Point of Aries.*

The unit of time is the *Day,* which is the period between two successive transits over the same branch of the meridian of the point of reference. The day is divided into 24 equal parts, called *Hours;* each hour is divided into 60 equal parts, called *Minutes,* and each minute into 60 equal parts, called *Seconds.*

273. Apparent or Solar Time.—The hour angle of the center of the sun affords a measure of *Apparent* or *Solar Time.* An *Apparent* or *Solar Day* is the interval of time between two successive transits over the same meridian of the center of the sun. It is *Apparent Noon* when the sun's hour circle coincides with the celestial meridian. This is the most natural and direct measure of time, and the unit of time adopted by the navigator at sea is the apparent solar day. Apparent noon is the time when the latitude can be most readily determined, and the ordinary method of determining the longitude by the sun involves a calculation to deduce the apparent time first.

Since, however, the intervals between the successive returns of the sun to the same meridian are not equal, apparent time can not be taken as a standard. The apparent day varies in length from two causes: first, the sun does not move in the equinoctial, the great circle perpendicular to the axis of rotation of the earth, but in the ecliptic; and, secondly, the sun's motion in the ecliptic is not uniform. Sometimes the sun describes an are of 57′ of the ecliptic, and sometimes an arc of 61′ in a day. At the points where the ecliptic and equinoctial intersect, the direction of the sun's apparent motion is inclined at an angle of 23° 27′ to the equinoctial, while at the solstices it moves in a direction parallel to the equinoctial.

274. Mean Time.—To avoid the irregularity of time caused by the want of uniformity in the sun's motion, a fictitious sun, called the *Mean Sun,* is supposed to move in the *equinoctial* with a uniform velocity that equals the *mean velocity of the true sun in the ecliptic;* so that the right ascension of the mean sun is equal to the mean celestial longitude of the true sun, it being understood that the difference between the true and mean celestial longitudes is zero at perihelion.

Mean time is the hour angle of the mean sun. A *Mean Day* is the interval between two successive transits of the mean sun over the meridian. *Mean Noon* is the instant when the mean sun's hour circle coincides with the meridian.

Mean time lapses uniformly; at certain times it agrees with apparent time, while sometimes it is behind, and at other times in advance of it. It is this time that is measured by the clocks in ordinary use, and to this the chronometers used by navigators are regulated.

275. The difference between apparent and mean time is called the *Equation of Time;* by this quantity, the conversion from one to the other of these times may be made. Its magnitude and the direction of its application may be found for any moment from the Nautical Almanac.

276. Sidereal Time.—*Sidereal Time* is the hour angle of the First Point of Aries. This point, which is identical with the vernal equinox, is the origin of all coordinates of right ascension. Since the position of the point is fixed in the celestial sphere and does not, like the sun, moon, and planets, have actual or apparent motion therein, it shares in this respect the properties of the fixed stars. It may therefore be said that intervals of sidereal time are those which are measured by the stars.

A *Sidereal Day* is the interval between two successive transits of the First Point of Aries across the same meridian. *Sidereal Noon* is the instant at which the hour circle of the First Point of Aries coincides with the meridian. In order to interconvert sidereal and mean times an element is tabulated in the Nautical Almanac. This is the *Sidereal Time of Mean Noon,* which is also the *Right Ascension of the Mean Sun.*

277. Civil and Astronomical Time.—The *Civil Day* commences at midnight and comprises the twenty-four hours until the following midnight. The hours are counted from 0 to 12, from midnight to noon; then, again, from 0 to 12, from noon to midnight. Thus the civil day is divided into two periods of twelve hours each, the first of which is marked a. m. (ante meridian), while the last is marked p. m. (post meridian).

The *Astronomical* or *Solar Day* commences at noon of the civil day of the same date. It comprises twenty-four hours, reckoned from 0 to 24, from noon of one day to noon of the next. Astronomical time (apparent or mean) is the hour angle of the sun (true or mean) measured to the westward throughout its entire circuit from the time of its upper transit on one day to the same instant of the next.

The civil day, therefore, begins twelve hours before the astronomical day, and a clear understanding of this fact is all that is required for interconverting these times. For example:

January 9, 2 a. m., civil time, is January 8, 14^h, astronomical time.

January 9, 2 p. m., civil time, is January 9, 2^h, astronomical time.

278. Hour Angle.—The *hour angle* of a heavenly body is the angle at the pole of the celestial concave between the declination circle of the heavenly body and the celestial meridian. It is measured by the arc of the celestial equator between the declination circle and the celestial meridian.

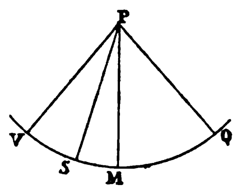

Fig. 35.

In figure 35 let P be the pole of the celestial sphere, of which VMQ is the equator, PQ the celestial meridian, and PM, PS, PV the declination circles of the mean sun, a heavenly body, and the First Point of Aries, respectively.

Then QPM, or its arc QM, is the hour angle of the mean sun, or the mean time; QPS, or QS, the hour angle of the heavenly body; QPV, or QV, the hour angle of the First Point of Aries, or the sidereal time; VPQ, or VQ, the right ascension of the meridian; VPS, or VS, the right ascension of the heavenly body; and VPM, or VM, the right ascension of the mean sun.

279. Time at Different Meridians. [a]—The hour angle of the true sun at any meridian is called the *local apparent time;* that of the mean sun, the *local mean time;* that of the First Point of Aries, the *local sidereal time.* The hour angles of the same body and points from Greenwich are respectively the *Greenwich apparent, mean,* and *sidereal times.* The difference between the local time at any meridian and the Greenwich time is equal to the longitude of that place from Greenwich expressed in time; the conversion from time to arc may be effected by a simple mathematical calculation or by the use of Table 7.

In comparing corresponding times of different meridians the most easterly meridian may be distinguished as that at which the time is *greatest* or *latest.*

[a] Standard Time.—This is the local mean time of meridians, known as standard meridians, located 15° of longitude apart commencing with the meridian of Greenwich as the initial meridian. The time of a standard meridian is used for the convenience of railways and in the affairs of everyday life in a tract extending as nearly as practicable 7½° each side of the standard meridian. The system of standard time zones has been extended over the oceanic areas, and the keeping standard time at sea has been instituted in the navies of the United States, Great Britain, France, and Italy. (See Hydrographic Office chart No. 5192.)

In figure 36 PM and PM′ represent the celestial meridians of two places, PS the declination circle through the sun, and PG the Greenwich meridian; let T_G = the Greenwich time = GPS;

T_M = the corresponding local time at all places on the meridian PM = MPS;
T_M' = the corresponding local time at all places on the meridian PM′ = M′PS;
Lo = west longitude of meridian PM = GPM; and
Lo′ = east longitude of meridian PM′ = GPM′.

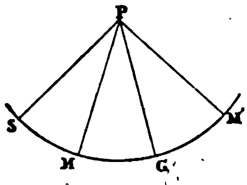

Fig. 36.

If west longitudes and hour angles be reckoned as positive, and east longitudes and hour angles as negative, we have:

$$Lo = T_G - T_M; \text{ and}$$
$$Lo' = T_G - T_M'; \text{ therefore}$$
$$Lo - Lo' = T_M' - T_M.$$

Thus it may be seen that the difference of longitude between two places equals the difference of their local times. This relation may be shown to hold for any two meridians whatsoever.

Both local and Greenwich times in the above formulæ must be reckoned westward, always from their respective meridians and from 0^h to 24^h; in other words, it is the astronomical time which should be used in all astronomical computations.

The formula $Lo = T_G - T_M$ is true for any kind of time, solar or sidereal; or, in general terms, T_G and T_M are the hour angles of any point of the sphere at the two meridians whose difference of longitude is Lo. S may be the sun (true or mean) or the vernal equinox.

280. Finding the Greenwich Time.—Since nearly every computation made by the navigator requires a knowledge of the Greenwich date and time as a preliminary to the use of the Nautical Almanac, the first operation necessary is to deduce from the local time the corresponding Greenwich date, either exact or approximate, and thence the Greenwich time expressed astronomically.

The formula is:

$$T_G = T_M + Lo,$$

remembering that west longitudes are positive, east longitudes are negative. Hence the following rule for converting local to Greenwich time:

Having expressed the local time astronomically, *add* the longitude if *west*, *subtract* it if *east;* the result is the corresponding Greenwich time.

Example: In longitude 81° 15′ W. the local time is, April, $15^d\ 10^h\ 17^m\ 30^s$ a. m. Required the Greenwich time.

Local Ast. time, April,	14^d	22^h	17^m	30^s
Longitude,	+	5	25	00
Greenwich time,	15	3	42	30

Example: In longitude 81° 15′ E. the local time is, August, $5^d\ 2^h\ 10^m\ 30^s$ p. m. Required the Greenwich time.

Local Ast. time, August,	5^d	2^h	10^m	30^s
Longitude,	—	5	25	00
Greenwich time,	4	20	45	30

Example: In longitude 17° 28′ W. the local time is, May, $1^d\ 3^h\ 10^m$ p. m. Required the Greenwich time.

Local Ast. time, May,	1^d	3^h	10^m	00^s
Longitude,	+	1	09	52
Greenwich time,	1	4	19	52

Example: In longitude 125° 30′ E. the local time is, May, $1^d\ 8^h\ 10^m\ 30^s$ a. m. Required the Greenwich time.

Local Ast. time, April,	30^d	20^h	10^m	30^s
Longitude,	–	8	22	00
Greenwich time,	30	11	48	30

281. From the preceding article we have:

$$T_G = T_M + Lo; \text{ hence,}$$
$$T_M = T_G - Lo;$$

thus it will be seen that, to find the local time corresponding to any Greenwich time, the above process is simply reversed.

Since all observations at sea are referred to chronometers regulated to Greenwich mean time, and as these instruments are usually marked on the dial from 0^h to 12^h, it becomes necessary to distinguish whether it is a. m. or p. m. at Greenwich. Therefore an approximate knowledge of the longitude and local time is necessary to determine the Greenwich date.

EXAMPLE: In longitude $5^h\ 00^m\ 00^s$ W., about $3^h\ 30^m$ p. m. April 15th, the Greenwich chronometer read $8^h\ 25^m$, and was fast of Gr. time $3^m\ 15^s$. Required the local astronomical time.

Approx. local time,	$15^d\ 3^h\ 30^m$	Gr. chro.,	$8^h\ 25^m\ 00^s$
Longitude,	+ 5 00	Corr.,	− 3 15
Approx. Gr. time,	15 8 30	Gr. Ast. time 15^d,	8 21 45

Gr. Ast. time 15^d,	$8^h\ 21^m\ 45^s$
Longitude,	−5 00 00
Local Ast. time 15^d,	3 21 45

EXAMPLE: In longitude $5^h\ 00^m\ 00^s$ E., about 8 a. m. May 3d, the Gr. chro. read $3^h\ 15^m\ 20^s$, and was fast of Gr. time $3^m\ 15^s$. Required the local astronomical time.

Approx. local time, May,	$2^d\ 20^h$	Gr. chro.,	$3^h\ 15^m\ 20^s$
Longitude,	− 5	Corr.,	− 3 15
Approx. Gr. time,	2 15	Gr. Ast. time 2^d,	15 12 05

Gr. Ast. time 2^d,	$15^h\ 12^m\ 05^s$
Longitude,	+ 5 00 00
Local Ast. time 2^d,	20 12 05

THE NAUTICAL ALMANAC.[a]

282. *The American Ephermeris and Nautical Almanac* is divided into three parts as follows: Part I, Ephemeris for the meridian of Greenwich, gives the ephemerides of the sun and moon, the geocentric and heliocentric positions of the major planets, the sun's coordinates, and other fundamental astronomical data for equidistant intervals of Greenwich mean time; Part II, Ephemeris for the meridian of Washington gives the ephemerides of the fixed stars, sun, moon, and major planets for transit over the meridian of Washington, and Part III, Phenomena, contains predictions of phenomena to be observed with data for their computation. Tables are also appended for the interconversion of mean and sidereal time and for finding the latitude and azimuth by an altitude of Polaris.

The American Nautical Almanac is a smaller book made up of extracts from the "Ephemeris and Almanac" just described, and is designed especially for the use of navigators, being adapted to the meridian of Greenwich. It contains the position of the sun and moon, together with the ephemerides of the planets Venus, Mars, Jupiter, and Saturn, and the apparent places of 55 stars for the first of each month and the Greenwich mean time of transit at Greenwich for each of these stars, also the mean places of 110 additional stars; solar and lunar eclipses are described, and the tables for the interconversion of mean and sidereal time and for finding the latitude by Polaris are included.

The elements dependent upon the sun and moon are placed in the first part of the book, arranged according to hours, days, and months of the year. The right ascension of the mean sun for the entire year is given at one opening, also, the mean time of sidereal noon at Greenwich; the declination of the sun, equation of time, the right ascension and declination of the moon and the moon's horizontal parallax and semidiameter are given for every even hour throughout the year. They must be taken from the Almanac for some definite instant of Greenwich mean time. In computations from observations that depend upon the time of the sun's meridian passage, at which instant the local apparent time is 0^h, and the Greenwich apparent time is equal to the longitude, if west, or to 24^h minus the longitude, if east, it becomes necessary to correct the equation of time for longitude, before it is applied

[a] See extracts from Ephemeris and Nautical Almanac for 1916, Appendix I.

to the Greenwich apparent time to obtain a Greenwich mean time for use in taking out other desired data. This Greenwich mean time is sufficiently correct for all practical purposes as the equation of time never changes more than $1^s.3$ in an hour.

283. Reduction of Elements.—The reduction of elements in the Nautical Almanac is usually accomplished by *Interpolation*, but in certain cases where extreme precision is necessary the method of *Second Differences* must be used.

The Ephemeris, being computed for the Greenwich meridian, contains the right ascensions, declinations, equations of time, and other elements for given equidistant intervals of Greenwich time. Hence, before the value of any of these quantities can be found for a given local time it is necessary to determine the corresponding Greenwich time. Should that time be one for which the Nautical Almanac gives the value of the required element, nothing more is necessary than to employ that value. But if the time falls between the Almanac times, the required quantity must be found by interpolation.

The Almanac contains the rate of change or difference of each of the principal quantities for some unit of time, and, unless great precision is required, the first differences only need be regarded. In order to use the difference columns to advantage, the Greenwich date should be expressed in the unit of time for which the difference is given. Thus, for using the hourly differences, the Greenwich time should be expressed in hours and decimal parts of an hour; when using the differences for one minute, the time should be in minutes and decimal parts of a minute. Instead of using decimal parts, some may prefer the use of aliquot parts.

Since the quantities in the Almanac are approximate numbers, given to a certain decimal, any interpolation of a lower order than that decimal is unnecessary work. Moreover, since, in computations at sea, the Greenwich time is more or less inexact, too great refinement need not be sought in reducing the Almanac elements.

Simple interpolation assumes that the differences of the quantities are proportional to the differences of the times; in other words, that the differences given in the Almanac are constant; this is seldom the case, but the error arising from the assumption will be smaller the less the interval between the times in the Almanac. Hence those quantities which vary most irregularly are given for the smallest units of time; as the variations are more regular, the units for which the differences are given increase.

In taking from the Almanac the elements relating to the fixed stars the data may be found either in the table which gives the "mean place" of each star for the year or in that which gives the "apparent place" occupied by each one on the first day of each month. As the annual variation of position of the fixed stars is small, the results will not vary greatly whichever table may be used. Yet, as it is proper to seek always the greatest attainable accuracy, the use of the table showing the exact positions is recommended.

284. To find from the Nautical Almanac a required element for any given time and place, it is first necessary to express the time astronomically and to convert it to Greenwich time and date. Then take from the Almanac, for the nearest given *preceding* instant, the required quantity, together with its corresponding "hourly" or "two-hourly difference," noting the name or sign in each case. Multiply the "hourly difference" by the number of hours and fraction of an hour, or use Table IV, N. A. (proportional parts), corresponding to the interval between the time for which the quantity is given in the Almanac and the time for which required; apply the correction thus obtained, having regard to its sign.

A modification of this rule may be adopted if the time for which the quantity is desired falls considerably nearer a *subsequent* time given in the Almanac than it does to one preceding; in this case the interpolation may be made backward, the sign of application of the correction being reversed.

Example: At a place in longitude 81° 15′ W., April 17, 1916, find the sun's declination and the equation of time at apparent noon.

Long. = 81° 15′ W. G. A. T. = $17^d\ 5^h\ 25^m = 17^d + 5^h.42$.

G. A. T., 17^d,	$5^h\ 25^m\ 00^s$	Eq. t., $17^d\ 4^h$,	$0^m\ 26^s.1$	H. D.,	$+0^s.6$
Eq. t.,	− 27	Corr.,	+ .8	Int.,	$1^h.42$
G. M. T., 17^d,	5 24 33	Eq. t., $17^d\ 5^h\ 25^m$,	0 26 .9	Corr.,	$+0^s.852$
	= $5^h.4$	(*Add* to *mean* time.)			

Dec., $17^d\ 4^h$,	10° 31′.0 N.	H. D.,	+0′.9
Corr.,	+ 1 .3	G. M. T.,	$1^h.4$
Dec., $17^d\ 5^h\ 25^m$,	10 32 .3 N.	Corr.,	+1′.26

Example: At a place in longitude 81° 15′ E., April 17, 1916, find the sun's declination and the equation of time at apparent noon.

Long. = 81° 15′ E. G. A. T. = $16^d\ 18^h\ 35^m = 17^d - 5^h.42$.

G. A. T., 16^d,	$18^h\ 35^m\ 00^s$	Eq. t., $16^d\ 18^h$,	$0^m\ 20^s.2$	H. D.,	$0^s.6$
Eq. t.,	− 0 20 .5	Corr.,	+ 0 .3	Int.,	$0^h.58$
G. M. T., 16^d,	18 34 39 .5	Eq. t., $16^d\ 18^h\ 35^m$,	0 20 .5	Corr.	$+0^s.348$
	= 18 .58	(*Add* to *mean* time.)			

Dec., $16^d\ 18^h$,	10° 22′.2 N.	H. D.,	+0′.9
Corr.,	+ .5	G. M. T.,	$0^h.58$
Dec., $16^d\ 18^h\ 35^m$,	10° 22′.7 N.	Corr.,	+0′.522

Example: April 15, 1916, at $11^h\ 55^m\ 30^s$ a. m., local mean time, in Long. 81° 15′ W., required the declination and semidiameter of the sun, the equation of time, and the right ascension, declination, horizontal parallax, and semidiameter of the moon and Jupiter.

Local mean time,	$14^d\ 23^h\ 55^m\ 30^s$
Longitude,	+ 5 25 00
Greenwich mean time,	15 5 20 30
	$15^d\ 5^h\ 20^m.5$
	$15^d\ 5^h.34$

For the Sun.

Dec., $15^d\ 4^h$,	9° 48′.5 N.	S. D., 15′ 58″	Eq. t., $15^d\ 4^h$,	$0^m\ 02^s.8$
Corr.,	+ 1 .2	(Same as at G. A. Noon.)	Corr.,	− 0 .8
Dec.,	9 49 .7 N.		Eq. t.,	0 02
H. D.,	+ 0′.9		H. D.,	− $0^s.6$
G. M. T.,	$1^h.34$		G. M. T.,	$1^h.34$
Corr.,	+ 1′.20		Corr.,	− $0^s.804$
				(*Subtract* from *mean* time.)

For the Moon.

R. A. $15^d\ 4^h$,	$11^h\ 28^m\ 14^s$	Hor. Par., $15^d\ 5^h.34$, 57′.1	Dec., $15^h\ 4^h$,	0° 39′.8 S.
Corr.,	+ 2 38	S. D., $15^d\ 5^h.34$, 15′.6	Corr.,	− 19 .8
R. A.,	11 30 52		Dec.,	0 59 .6 S.
H. D.,	+ 118^s		H. D.,	− 14′.7
G. M. T.,	$1^h.34$		G. M. T.,	$1^h.34$
Corr.,	+ { 158^s / $2^m\ 38^s$		Corr	− 19′.8
(By proportional parts Table IV, N. A.)			(By proportional parts Table IV, N. A.)	
R. A., $15^d\ 6^h$,	$11^h\ 32^m\ 10^s$		Dec., $15^d\ 6^h$,	(−)1° 09′.3 S.
Corr., $39^m.5$,	− 1 18		Corr., $39^m.5$,	+ 9 .7
R. A.,	11 30 52		Dec.,	0 59 .6 S.

For Jupiter.

R. A., $15^d\ 0^h$.,	$0^h\ 56^m\ 28^s$	Hor. Par., 15^d, 0′.02	Dec., $15^d\ 0^h$,	+ 4° 51′.5 N.
Corr.,	+ 12	S. D., 15^d, 0′.26	Corr.,	+ 1 .2
R. A.,	0 56 40		Dec.,	4 52 .7 N.
H. D.,	+ $2^s.25$		H. D.,	+ 0′.23
G. M. T.,	$5^h.34$		G. M. T.,	$5^h.34$
Corr.,	+ 12^s		Corr.,	+ 1′.22
(Prop. parts Table IV, N. A. (See p. 253*b*.))			(Prop. parts Table IV, N. A.)	
R. A., $15^d\ 0^h$,	$0^h\ 56^m\ 28^s$		Dec., $15^d\ 0^h$,	+ 4° 51′.5 N.
Corr., $5^h\ 20^m$,	+ 12		Corr., $5^h\ 20^m$,	+ 1 .2
R. A.,	0 56 40		Dec.,	4 52 .7 N.

285. Should greater precision be required than that attainable by simple interpolation, resort must be had to the reduction for second differences, for which use the Ephemeris and Nautical Almanac.

The differences between successive values of the quantities given in the Ephemeris and Nautical Almanac are called the *first differences;* the differences between successive first differences are called the *second differences.* Simple interpolation, which satisfies the necessities of sea computations, assumes the first differences to be constant; but if the variation of the first differences be regarded, a further interpolation is required for the second difference.

The difference for a unit of time in the American Ephemeris and Nautical Almanac abreast any element expresses the rate at which the element is changing at that precise instant of Greenwich time. Now, regarding the second difference as constant, the first difference varies uniformly with the Greenwich time; therefore its value may be found for any intermediate time by simple interpolation.

Hence the following rule for second differences: Employ the interpolated value of the first difference which corresponds to the *middle* of the interval for which the correction is to be computed.

EXAMPLE: For the Greenwich date 1916, April, $10^d\ 18^h\ 25^m\ 30^s$, find the moon's declination.

Dec., 18^h,	(+)21° 09′ 41″.8 N.	First diff.,	− 8″.522	Second diff.,	−0″.096
Corr.,	− 3 37 .8	Corr.,	− 0 .020	Interval,	$+0^h.213$
Dec.,	21 06 04 N.	M. D.,	− 8 .542	Corr.,	−0″.020
		No. min.,	+ $25^m.5$		
		Corr.,	− {217″.8 / 3′ 37″.8}		

The difference for one minute being −8″.522 at 18^h, and −8″.618 at 19^h, the difference for one minute undergoes a change of −0″.096 during one hour. The time for which it is desired to obtain the difference is at the middle instant between $18^h\ 0^m$ and $18^h\ 25^m.5$—that is, at $18^h\ 12^m.75$, or its equivalent, $18^h.213$. With a change of −0″.096 in one hour, the change in $0^h.213$ is readily obtainable; correcting the minute's difference at $18^h.0$ accordingly, the process of correcting the declination becomes the same as in simple interpolation.

CONVERSION OF TIMES.

286. *Conversion of Time* is the process by which any instant of time that is defined according to one system of reckoning may be defined according to some other system; and also by which any interval of time expressed in units of one system may be converted into units of another.

287. SIDEREAL AND MEAN TIME.—Mean time is the hour angle of the Mean Sun; sidereal time is the hour angle of the First Point of Aries. Since the Right Ascension of the Mean Sun is the angular distance between the hour circles of the First Point of Aries and of the Mean Sun, mean time may be converted into sidereal time by adding to it the Right Ascension of the Mean Sun; and similarly, sidereal time may be converted into mean time by subtracting from it the Right Ascension of the Mean Sun.

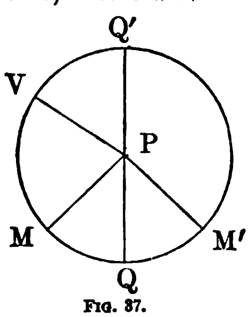

FIG. 37.

This is explained in figure 37, which represents a projection of the celestial sphere upon the equator. If P be the pole; QPQ′, the meridian; V, the First Point of Aries; M, the position of the mean sun (west of the meridian); then QPV, or the arc QV, is the sidereal time; QPM, or the arc QM, is the mean time; and VPM, or the arc VM, is the Right Ascension of the Mean Sun. From this it will appear that:

$$QV = QM + VM, \text{ or}$$

$$\text{Sidereal time} = \text{Mean time} + \text{Right Ascension of Mean Sun.}$$

If the mean sun be on the opposite side of the meridian, at M′, then the mean time equals $24^h - M'Q$. In this case:

$$QV = VM' - M'Q, \text{ or}$$
$$\text{Sidereal time} = \text{Right Ascension of Mean Sun} - (24^h - \text{Mean time}),$$
$$= \text{Right Ascension of Mean Sun} + \text{Mean time} - 24^h.$$

Right ascension being measured to the east and hour angle to the west, the sidereal time will therefore always equal the sum of these two; but 24^h must be subtracted when the sum exceeds that amount.

From the preceding equations, we also have:

$$QM = QV - VM; \text{ and}$$
$$M'Q = VM' - QV, \text{ or}$$
$$(24^h - M'Q) = (24^h + QV) - VM'.$$

From this it may be seen that the mean time equals the sidereal time *minus* the Right Ascension of the Mean Sun, but the former must be increased by 24^h when necessary to make the subtraction possible.

288. Apparent and Mean Times.—Apparent time is the angle between the meridian and the hour circle which contains the center of the sun; mean time is the angle between the meridian and the hour circle which contains the mean sun. Since the equation of time represents the angle between the hour circles of the mean and apparent suns, it is clear that the conversion of mean time to apparent time may be accomplished by the application of the equation of time, with its proper sign, to the mean time; and the reverse operation by the application of the same quantity, in an opposite direction, to the apparent time.

The resemblance of these operations to the interconversion of mean and sidereal times may be observed if, in figure 37, we assume that PV is the hour circle of the true sun, PM remaining that of the mean sun; then the arc QM will be the mean time; QV, the apparent time; and VM, the equation of time; whence we have as before:

$$QV = QM + VM, \text{ or}$$
$$\text{Apparent time} = \text{Mean time} + \text{Equation of time};$$

the equation of time will be positive or negative according to the relative position of the two suns.

289. Sidereal and Mean Time Intervals.—The sidereal year consists of 366.25636 sidereal days or of 365.25636 mean solar days. If, therefore, M be any interval of mean time, and S the corresponding interval of sidereal time, the relations between the two may be expressed as follows:

$$\frac{S}{M} = \frac{366.25636}{365.25636} = 1.0027379;$$

$$\frac{M}{S} = \frac{365.25636}{366.25636} = 0.9972696.$$

$$\text{Therefore, } S = 1.0027379\ M = M + .0027379\ M;$$
$$M = 0.9972696\ S = S - .0027304\ S.$$

If $M = 24^h$, $S = 24^h + 3^m\ 56^s.6$; or, in a mean solar day, sidereal time gains on mean time $3^m\ 56^s.6$, the gain each hour being $9^s.8565$.

If $S = 24^h$, $M = 24^h - 3^m\ 55^s.9$; or, in a sidereal day, mean time loses on sidereal time $3^m\ 55^s.9$, the loss each hour being $9^s.8296$.

If M and S be expressed in hours and fractional parts thereof,

$$S = M + 9^s.8565\ M;$$
$$M = S - 9^s.8296\ S.$$

Tables for the conversion of the intervals of mean into those of sidereal time and the reverse are based upon these relations. Tables 8 and 9 of this work give the values for making these conversions, and similar tables are to be found in the Nautical Almanac.

290. To Convert Mean Solar into Sidereal Time.—Apply to the local mean time the longitude, adding if west and subtracting if east, and thus obtain the Greenwich mean time. Take from the Nautical Almanac the Right Ascension of the Mean Sun at Greenwich mean noon, and correct it for the Greenwich mean time by Table III, N. A., or Table 9 (Bowditch), or by the hourly difference of $9^s.857$. Add to the local mean time this corrected right ascension, rejecting 24^h if the sum is greater than that amount. The result will be the local sidereal time.

Example: April 22, 1916, in Long. 81° 15′ W., the local mean time is $2^h\ 00^m\ 00^s$ p. m. Required the corresponding local sidereal time.

L. M. T.,	22^d	2^h	00^m	00^s	R. A. M. S., $22^d\ 0^h$,	2^h	00^m	$50^s.4$	L. M. T.,		2^h	00^m	00^s
Long.,	+	5	25	00	Red. for $7^h\ 25^m$ (Tab. 9), +		1	13 .1	R. A. M. S., +		2	02	03 .5
G. M. T.,	22	7	25	00	R. A. M. S., $7^h\ 25^m$,	2	02	03 .5	L. S. T.,		4	02	03 .5

Example: April 22, 1916, in Long. 75° E., the local mean time is $4^h\ 00^m\ 00^s$ a. m. Required the local sidereal time.

L. M. T.,	21^d	16^h	00^m	00^s	R. A. M. S., $21^d\ 0^h$,	1^h	56^m	$53^s.8$	L. M. T.,	21^d	16^h	00^m	00^s
Long.,	−	5	00	00	Red. for 11^h (Tab. 9), +		1	48 .4	R. A. M. S., +		1	58	42 .2
G. M. T.,	21	11	00	00	R. A. M. S., 11^h,	1	58	42 .2	L. S. T.,	21	17	58	42 .2

In these examples the reduction of the R. A. M. S. has formed a separate operation in order to make clear the process. It would be as accurate to add together directly L. M. T., R. A. M. S., and Red., and the work would thus be rendered more brief.

291. To Convert Sidereal into Mean Solar Time.—Take from the Nautical Almanac the Right Ascension of the Mean Sun for Greenwich mean noon of the given astronomical day, and apply to it the reduction for longitude, either by Table 9 or by the hourly difference of $9^s.857$, and the result will be the Right Ascension of the Mean Sun at local mean noon, which is equivalent to the local sidereal time at that instant. Subtract this from the given local sidereal time (adding 24^h to the latter if necessary), and the result will be the interval from local mean noon, expressed in units of sidereal time. Convert this sidereal time interval into a mean time interval by subtracting the reduction as given by Table II, N. A., or Table 8, or by the hourly difference of $9^s.830$; the result will be the local mean time.

Example: April 22, 1916, a. m., in Long. 75° E., the local sidereal time is $17^h\ 58^m\ 42^s.2$. What is the local mean time?

Astronomical day, April 21.

L. S. T.,	17^h	58^m	$42^s.2$	R. A. M. S., Gr. $21^d\ 0^h$,		1^h	56^m	$53^s.8$
R. A. M. S.,	− 1	56	04 .5	Red. for -5^h long. (Tab. 9),	−			49 .3
Sid. interval from L. M. noon,	16	02	37 .7	R. A. M. S., local 0^h,		1	56	04 .5
Red. for sid. interval (Tab. 8),		2	37 .7					
L. M. T., 21^d,	16	00	00 .0					

Example: April 22, 1916, p. m., at a place in Long. 81° 15′ W., the sidereal time is $4^h\ 02^m\ 03^s.5$. What is the corresponding mean time?

Astronomical day, April 22.

L. S. T.,	4^h	02^m	$03^s.5$	R. A. M. S., Gr. $22^d\ 0^h$,	2^h	00^m	$50^s.4$
R. A. M. S.,	− 2	01	43 .8	Red. for $+5^h\ 25^m$ long. (Tab. 9), +		0	53 .4
Sid. interval from L. M. Noon,	2	00	19 .7	R. A. M. S., local 0^h,	2	01	43 .8
Red. for sid. interval (Tab. 8), −		0	19 .7				
L. M. T., 22^d,	2	00	00 .0				

292. To Convert Mean into Apparent Time and the Reverse.—Find the Greenwich time corresponding to the given local time. If apparent time is given, find the Greenwich apparent time and take the equation of time from the Almanac. If mean time, find the Greenwich mean time, correct the equation of time for the required instant and apply it with its proper sign to the given time.

EXAMPLE: April 21, 1916, in Long. 81° 15′ W., find the local apparent time corresponding to a local mean time of $3^h\ 05^m\ 00^s$ p. m.

L. M. T.,	$21^d\ 3^h\ 05^m\ 00^s$	L. M. T.,	$21^d\ 3^h\ 05^m\ 00^s$	Eq. t., 8^h,	$1^m\ 21^s.3$
Long., +	5 25 00	Eq. t., +	1 21 .5	Corr., +	0. 2
G. M. T.,	21 8 30 00	L. A. T.,	21 3 06 21 .5	Eq. t.,	1 21. 5
				H. D., +	$0^s.5$
				G. M. T., +	$0^h.5$
				Corr., +	$0^s.25$
					(*Add* to *mean* time.)

EXAMPLE: April 3, 1916, in Long. 81° 15′ E., the local apparent time is $8^h\ 45^m\ 00^s$ a. m. Required the mean time.

L. A. T.,	$2^d\ 20^h\ 45^m\ 00^s$	L. A. T.,	$2^d\ 20^h\ 45^m\ 00^s$	Eq. t., 14^h,	$3^m\ 30^s.6$
Long., −	5 25 00	Eq. t., +	3 29 .7	Corr., −	0 .9
G. A. T.,	2 15 20 00	L. M. T.,	2 20 48 29 .7	Eq. t.,	3 29 .7
				H. D., −	$0^s.7$
				Int., +	$1^h.33$
				Corr., −	$0^s.93$
					(*Add* to *apparent* time.)

293. TO FIND THE HOUR ANGLE OF A BODY FROM THE TIME, AND THE REVERSE.—In figure 37, if M and M′ represent the positions of celestial bodies instead of those of the mean sun as before assumed, then the hour angles of the bodies will be Q M and 24^h − M′ Q, respectively, and their right ascensions will be V M and V M′.

As before, we have:

$$
\begin{aligned}
QV &= QM + VM,\\
&= VM' - M'Q;\\
QM &= QV - VM;\\
M'Q &= VM' - VQ, \text{ or}\\
(24^h - M'Q) &= (24^h + QV) - VM'.
\end{aligned}
$$

Substituting, therefore, *hour angle of the body* for *mean time*, and *right ascension of the body* for *Right Ascension of the Mean Sun*, the rules previously given for the conversion of mean and sidereal times will be applicable for the conversion of hour angle and sidereal time. Thus, the sidereal time is equal to the sum of the right ascension of the body and its hour angle, subtracting 24^h when the sum exceeds that amount; and the hour angle equals the sidereal time *minus* the right ascension of the body, 24^h being added to the former when necessary to render the subtraction possible.

EXAMPLE: In Long. 81° 15′ W., on April 25, 1916, at $12^h\ 10^m\ 30^s$ (astronomical) mean time, find the hour angle of Sirius.

L. M. T.,	$12^h\ 10^m\ 30^s$	L. M. T.,	$12^h\ 10^m\ 30^s.0$
Long.,	+ 5 25 00	R. A. M. S., 0^h, +	2 12 40 .0
		Red. (Tab. 9), +	2 53 .4
G. M. T.,	17 35 30	L. S. T.,	14 26 03 .4
		R. A. Sirius,	− 6 41 27 .6
		H. A. Sirius,	7 44 35 .8

EXAMPLE: May 9, 1916, Arcturus being $2^h\ 27^m\ 42^s.52$ east of the meridian, find the local sidereal time.

	$24^h\ 00^m\ 00^s$	H. A.,	$21^h\ 32^m\ 17^s.48$
H. A.,	2 27 42.52 E.	R. A.,	+14 11 52 .9
H. A.,	21 32 17.48 W.	L. S. T.,	11 44 10 .38

Or thus:

H. A.,	− $2^h\ 27^m\ 42^s.52$
R. A.,	+14 11 52 .9
L. S. T.,	11 44 10 .38

294. Many navigators find the conversion of time much simplified and more easily grasped by roughly plotting the elements as they are presented in any given case, in a figure drawn on the plane of the celestial equator. Noting the known elements and the elements required to be found, a study of the figure shows very quickly how to combine the known elements to get the unknown elements.

Following this method, the examples of articles 290, 291, and 293 are here solved as an alternative to the preceding treatment, since it is found that, for many who have learned this method of procedure in the beginning, every difficulty in reckoning or converting time has been obviated. Although the explanation may appear somewhat long, the actual plotting and solution of any given case take only a few seconds when the method is understood. In the figures, P represents the elevated pole; Q, the intersection of the local meridian with the equator; G, the intersection of the meridian of Greenwich with the equator; V, the First Point of Aries (Vernal Equinox); S_m, the mean sun; S_a, the apparent sun; and ∗, a star or planet.

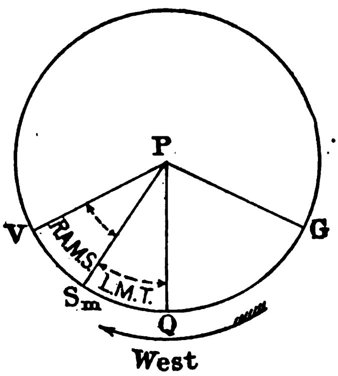

FIG. 38.

FIRST EXAMPLE OF ARTICLE 290. (SEE FIGURE 38.)

Draw a circle to represent the plane of the celestial equator, P being the projection of the pole, and PQ the projection of the local meridian. From P draw the projection of the hour circle of the Greenwich meridian which (since the longitude is west) is laid off to the right or eastward of the local meridian so that the arc QG equals the longitude. The arrow indicates westerly direction and shows the direction in which the hour circles of the heavenly bodies move around the circle on the earth's axis. The L. M. T. being p. m., we lay off the hour circle of the mean sun to the westward of the local meridian so that the arc QS_m equals the L. M. T. We see at once from the figure that the G. M. T. (the position of the hour circle of the mean sun, S_m, with reference to the Greenwich meridian) is the arc GQS_m, which equals Long. + L. M. T. Having thus found the G. M. T., we can find the right ascension of the mean sun at that instant from the Nautical Almanac (picked out for the day and corrected for the G. M. T.) which, in this case, is $2^h\ 02^m\ 03^s.5$. The correction is (+) or additive to the angle which represents the R. A. M. S. for Greenwich Mean Noon because this angle has been increased by this amount owing to the gain of the Vernal Equinox over the mean sun for the angle through which the mean sun has traveled from the Greenwich meridian. The mean sun is to the eastward of the Vernal Equinox by the amount of its right ascension. We therefore lay off PV, the hour circle of the Vernal Equinox, so that the arc VS_m equals the R. A. M. S. Since the L. S. T. equals the H. A. of the Vernal Equinox, we see at once from the figure that the L. S. T. equals R. A. M. S. + L. M. T.

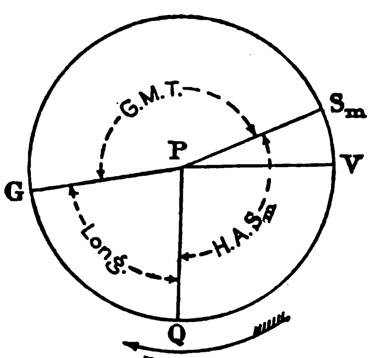

FIG. 39.

SECOND EXAMPLE OF ARTICLE 290. (SEE FIGURE 39.)

Draw a circle to represent the plane of the celestial equator. Project the pole P and the local meridian PQ. Draw the arrow pointed west to show the direction in which the hour circles move. Since the longitude is east, we know that the Greenwich meridian is to the westward of the local meridian, and we draw PG, the Greenwich meridian, so that the arc QG equals the longitude, equals 5 hours. Since the L. M. T. is $4^h\ 00^m\ 00^s$ a. m., we know that it will be $12^h - 4^h$ equals 8^h before the sun crosses the local meridian; hence we lay off the arc QS_m to equal the sun's H. A., which equals 8^h, and draw PS_m, the hour circle of the mean sun. We see from the figure that the hour angle of the mean sun from Greenwich (G. M. T.) is equal to 24^h – (Long. + H. A. S_m), and that, since the mean sun must travel around the arc to the west from S_m to G to make the time 0 hours on April 22 at

Greenwich, the date must be April 21, and the G. M. T. is 11 hours. For this Greenwich date, we get, from the Nautical Almanac (corrected for G. M. T.) the R. A. M. S. equal to $1^h\ 58^m\ 42^s.2$, which is the amount the hour circle of the mean sun is to the eastward of the hour circle of the Vernal Equinox. The correction is + or additive for the reason given in the preceding example. Lay off the arc S_mV equal to the R. A. M. S. and draw the hour circle of the Vernal Equinox PV. An inspection of the figure shows us that the L. S. T. is the arc QGV which is equal to the Long. + G. M. T. + R. A. M. S., or to the L. M. T. + the R. A. M. S. We also see that L. M. T. equals the Long. + G. M. T.

FIRST EXAMPLE OF ARTICLE 291. (SEE FIGURE 40.)

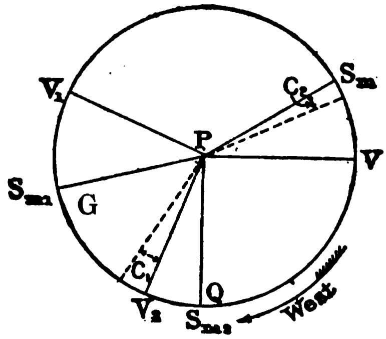

FIG. 40.

Draw the figure as shown, laying off the longitude equal to 5 hours east, to the westward from Q, thus finding the Greenwich meridian G. The given L. S. T. is 18 hours, so lay off QV (equal to 18 hours) to the westward from Q, given the position of V, the Vernal Equinox or First Point of Aries, for the instant desired. The problem is to plot the position of the mean sun at this instant, and thence find its local hour angle, or the L. M. T. We plot this position of the mean sun by laying off its right ascension to the eastward from V. The R. A. M. S. is found from the Almanac for a particular instant which is at Greenwich mean noon of the astronomical date, April 21, and which we find is $1^h\ 56^m\ 53^s.8$. Plot in S_{m_1}, over the Greenwich meridian and lay off this angle GV_1, to the westward from G, giving us the position of V at Greenwich mean noon. As we are reckoning hour angles from the local meridian, we must move the sun back to Q and find the position V_2 at the instant of local mean noon. To find V_2 we must find the angle QV_2 which will be less than GV_1, as the First Point of Aries always advances faster toward the west than the mean sun. The amount of this gain of the Vernal Equinox over the mean sun depends on the angular distance through which the mean sun travels, i. e., in this case from Q to G equals the longitude, equals 5 hours. From Table 9 we find the gain, which is represented by the sector C_1 in the figure, to be $49^s.3$ for the 5 hours, so that QV_2 equals $GV_1 - 49^s.3$, equals $1^h\ 56^m\ 53^s.8 - 49^s.3$, equals $1^h\ 56^m\ 04^s.5$. Now we have the position V_2 for the instant of time when the mean sun was at Q, that is for the position S_{m_2} or local mean noon. For the instant of time desired the Vernal Equinox is not at V_2 but at V and at this instant we must find S_{m_2}. The Vernal Equinox has moved from V_2 to the westward to V or through the arc V_2 V which equals $QV - QV_2$, equals $17^h\ 58^m\ 42^s.2 - 1^h\ 56^m\ 04^s.5$, equals $16^h\ 02^m\ 37^s.7$, which is called a sidereal interval. During this travel of the Vernal Equinox the mean sun will lose a certain angular amount on the Vernal Equinox, depending on the travel of the latter, which travel is $16^h\ 02^m\ 37^s.7$. From Table 8, we find for this travel that the loss will be $2^m\ 37^s.7$, which is represented by the sector C_2 in the figure, so that the angle QS_m is $V_2\ V - 2^m\ 37^s.7$, equals $16^h\ 02^m\ 37^s.7 - 2^m\ 37^s.7$, equals $16^h\ 00^m\ 00^s$, which, from the figure, equals the desired L. M. T.

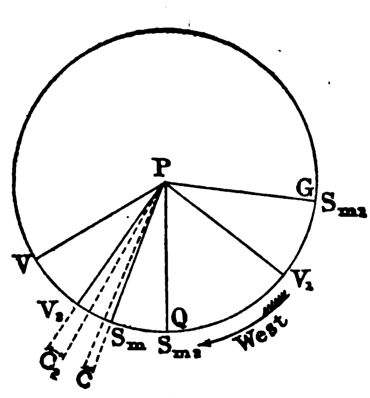

FIG. 41.

SECOND EXAMPLE OF ARTICLE 291. (SEE FIGURE 41.)

Draw the figure as shown, laying off the longitude equal to 5^h west, to the eastward from Q, thus finding the Greenwich meridian G. The problem is similar to the above problem except that in moving the mean sun from G to Q we see that the angle $S_{m_1}\ V_1$ is increased to find $S_{m_2}\ V_2$, as the Vernal Equinox has gained a certain amount on the mean sun during the travel of the sun to the westward from G to Q. For the travel of V_2 to V, the mean sun will travel from S_{m_2} to S_m, losing a certain amount on the Vernal Equinox for the travel of V_2 V of the latter, and we find QS_m equals the L. M. T.

First Example of Article 293. (See Figure 42.)

Draw the figure as explained above, using longitude given equals 5 hours west, and L. M. T. given, 12 hours (+). Then G. M. T. equals 12+5 or 17 hours (+) of April 25. For this instant of time the mean sun is plotted at S_m.

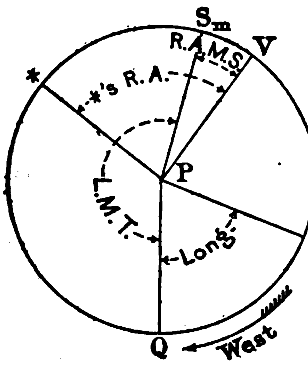

Fig. 42.

Now the problem is, knowing the positions of G, Q, and S_m, to find the position of the given star on the diagram, and thence its local hour angle. If we can find the relative angles from the mean sun and from the star to some third object, we can plot this third object and find the required hour angle of the star. The third object is the First Point of Aries (the Vernal Equinox) and the angles from the mean sun and from the star are the right ascensions of the mean sun and the star. The right ascension of the mean sun is found from the Almanac, not for the instant we want, but for the Greenwich mean noon of the date. This R. A. must be increased by a correction for the angle through which the mean sun has traveled since noon, — the G. M. T. In the problem the R. A. M. S. so increased is 2 hours, so we lay off S_mV from S_m to the westward 2 hours, plotting the position of the Vernal Equinox at the desired instant. From the Almanac we find the R. A. of the star to be 6 hours, and we lay off V ✻ equal to 6 hours to the eastward. The required local hour angle of the star is then Q ✻ which equals $QS_m + VS_m - V$ ✻ equals L. M. T. + R. A. M. S. − R. A. equals $12^h + 2^h - 6^h$ equals 8 hours.

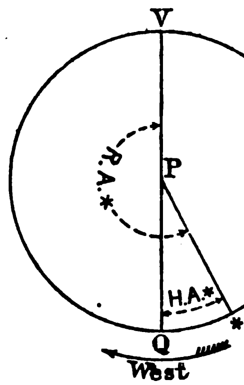

Fig. 43.

Second Example of Article 293. (See Figure 43.)

Draw the figure as before. The problem is, knowing the position of the star at a certain instant, to find the L. S. T., so we must plot the position of the star, then that of the Vernal Equinox. The local hour angle of the latter is the required L. S. T.

The hour angle of the star is given as 2 hours, bearing east from the meridian, so lay off Q ✻ = 2 hours to the east from Q. Now find from the Almanac the R. A. of the ✻ which is 14 hours, and lay off ✻ V equal to 14^h to the westward from ✻. The L. S. T. is then QV, equals V ✻ − Q ✻, equals the R. A. ✻ − H. A. ✻, equals $14^h - 2^h$ equals 12 hours.

When doubt exists as to the Greenwich date the navigator, by plotting the data in exactly the same way as explained above, can at once remove all doubt on the subject and can get the correct G. M. T.

CHAPTER X.

CORRECTION OF OBSERVED ALTITUDES.

294. The *true altitude* of a heavenly body at any place on the earth's surface is the altitude of its center, as it would be measured by an observer at the center of the earth, above the plane passed through the center of the earth at right angles to the direction of the zenith.

The *observed altitude* of a heavenly body, as measured at sea, may be converted to the true altitude by the application of the following-named corrections: *Index Correction*, *Dip*, *Refraction*, *Parallax*, and *Semidiameter*. The corrections for parallax and semidiameter are of inappreciable magnitude in observations of the fixed stars, and with planets are so small that they need only be regarded in refined calculations. In observations with the artificial horizon there is no correction for dip.

For theoretical accuracy, the corrections should be applied in the order in which they are named, but in ordinary nautical practice the order of application makes no material difference, except in the case of the parallax of the moon as explained in article 306; and hence, instead of turning to the separate tables referred to in the following articles as containing these corrections, their combined amount, given in Table 46 and Table 49, may be applied to observed altitudes of the heavenly bodies, after the manner shown in article 308.

INDEX CORRECTION.

295. This correction is fully explained in articles 249 and 250, Chapter VIII.

REFRACTION.

296. It is known by various experiments that the rays of light deviate from their rectilinear course in passing obliquely from one medium into another of a different density; if the latter be more dense, the ray will be bent toward the perpendicular to the line of junction of the media; if less dense, it will be bent away from that perpendicular.

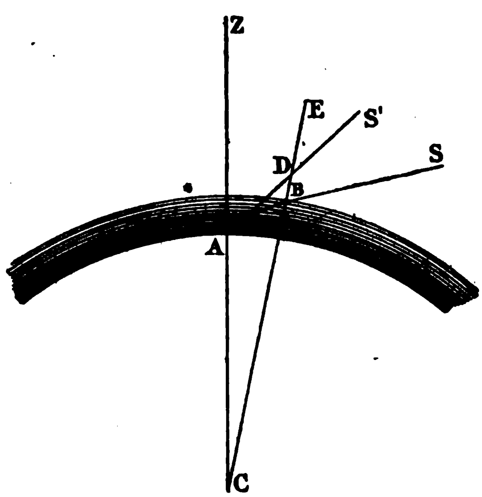

FIG. 44.

The ray of light before entering the second medium is called the *incident* ray; after it enters the second medium it is called the *refracted* ray, and the difference of direction of the two is called the *refraction*.

The rays of light from a heavenly body must pass through the atmosphere before reaching the eye of an observer upon the surface of the earth. The earth's atmosphere is not of a uniform density, but is most dense near the earth's surface, gradually decreasing in density toward its upper limit; hence the path of a ray of light, by passing from a rarer medium into one continually increasing density becomes a curve, which is concave toward the earth. The last direction of the ray is that of a tangent to the curved path at the eye of the observer, and the difference of the direction of the ray before entering the atmosphere and this last direction constitutes the refraction.

297. To illustrate this, consider the earth's atmosphere as shown in figure 44; let SB be a ray from a star S, entering the atmosphere at B, and bent into the curve BA; then the apparent direction of the star is AS′, the tangent to the curve at the point A, the refraction being the angle between the lines BS and AS′. If CAZ is the vertical line of the observer, by a law of optics the vertical plane of the observer which contains the tangent AS′ must also contain the whole curve BA and the incident ray BS. Hence refraction increases the apparent altitude of a star without affecting its azimuth.

At the zenith the refraction is nothing. The less the altitude the more obliquely the rays enter the atmosphere and the greater will be the refraction. At the horizon the refraction is the greatest.

298. The refraction for a mean state of the atmosphere (barometer 30^{in}, Fahr. thermometer 50°) is given in Table 20 A; the combined refraction and sun's parallax in Table 20 B; and the combined refraction and moon's parallax in Table 24.

Since the amount of the refraction depends upon the density of the atmosphere, and the density varies with the pressure and the temperature, which are indicated by the barometer and thermometer, the *true* refraction is found by applying to the mean refraction the corrections to be found in Tables 21 and 22; these are deduced from Bessel's formulæ, and are regarded as the most reliable tables constructed. It should be remembered, however, that under certain conditions of the atmosphere a very extraordinary deflection occurs in rays of light which reach the observer's eye from low altitudes (that is, from points near the visible horizon), the amount of which is not covered by the ordinary corrections for pressure and temperature; the error thus created is discussed under *Dip* (art. 301); on account of it, altitudes less than 10° should be avoided.

EXAMPLE: Required the refraction for the apparent altitude 5°, when the thermometer is at 20° and the barometer at $30^{in}.67$.

The mean refraction by Table 20 A is,	9′ 52″
The correction for height of barometer is,	+ 13
The correction for the temperature,	+ 42
True refraction,	10 47

299. The correction for refraction should always be subtracted, as also that for combined refraction and parallax of the sun; the correction for combined refraction and parallax of the moon is invariably additive.

DIP.

300. *Dip of the Horizon* is the angle of depression of the visible sea horizon below the true horizon, due to the elevation of the eye of the observer above the level of the sea.

In figure 45 suppose A to be the position of an observer whose height above the level of the sea is AB. CAZ is the true vertical at the position of the observer, and AH is the direction of the true horizon, S being an observed heavenly body. Draw ATH′ tangent to the earth's surface at T. Disregarding refraction, T will be the most distant point visible from A. Owing to refraction, however, the most distant visible point of the earth's surface is more remote from the observer than the point T, and is to be found at a point T′, in figure 46. But to an observer at A the point T′ will appear to lie in the direction of AH″, the tangent at A to the curve AT′. If the vertical plane were revolved about CZ as an axis, the line AH would generate the plane of the true horizon, while the point T′ would generate a small circle of the terrestrial sphere called the *Visible* or *Sea Horizon*. The *Dip of the Horizon* is HAH″, being the angle between the true horizon and the apparent direction of the sea horizon. Values of the dip are given in Table 14 for various heights of the observer's eye, and in the calculation of the table allowance has been made for the effect of atmospheric refraction as it exists under normal conditions.

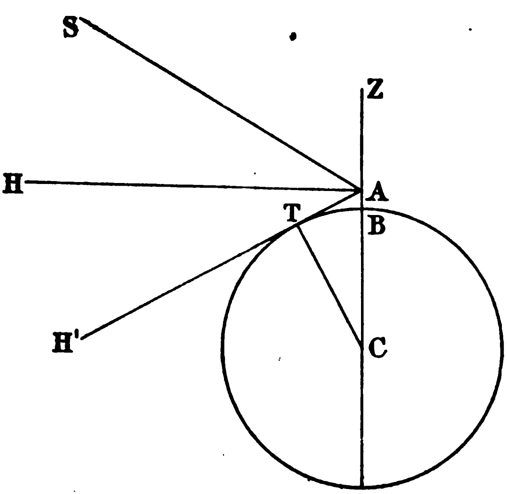

FIG. 45.

301. The fact must be emphasized, however, that under certain conditions the deflection of the ray in its path from the horizon to the eye is so irregular as to give a value of the dip widely different from that which is tabulated for the mean state of atmosphere. These irregularities usually occur when there exists a material difference between the temperature of the sea water and that of the air, and they attain a maximum value in calm or nearly calm weather, when the lack of circulation permits the air to arrange itself in a series of horizontal strata of different densities, the denser strata being below when the air is warmer, and the reverse condition obtaining when the air is cooler. The effect of such an arrangement is that a ray of light from the horizon in passing through media of different densities, undergoes a refraction quite unlike that which occurs in the atmosphere of much more nearly homogeneous density that exists under normal conditions.

Various methods have been suggested for computing the amount of dip for different relative values of temperature of air and water, but none of these afford a satisfactory solution, there being so many elements involved which are not susceptible of determination by an observer on shipboard that it will always be difficult to arrive at results that may be depended upon.

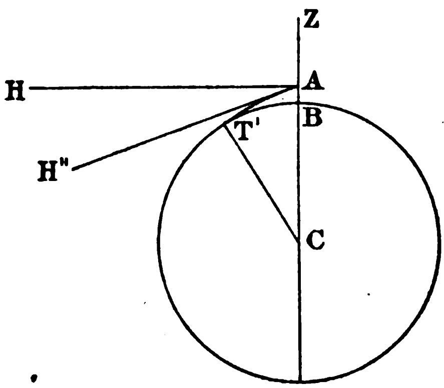

FIG. 46.

As the amount of difference between the actual and tabulated values of the dip due to this cause may sometimes be very considerable—reliable observations having frequently placed it above 10′, and values as high as 32′ having been recorded—it is necessary for the navigator to be on his guard against the errors thus produced, and to recognize the possible inaccuracy of all results derived from observations taken under unfavorable conditions. Without attempting to give any method for the determination of the amount of the extraordinary variation in dip, the following rules may indicate to the navigator the conditions under which caution must be observed, and the direction of probable error:

(*a*) A displacement of the horizon should always be suspected when there is a marked difference between the temperatures of air and sea water; this fact should be especially kept in mind in regions such as those of the Red Sea and the Gulf Stream, where the difference frequently exists.

(*b*) The error in the tabulated value of the dip will increase with an increase in the difference of temperature, and will diminish with an increase in the force of the wind.

(*c*) The error will decrease with the height of the observer's eye; hence it is expedient, especially when error is suspected, to make the observation from the most elevated position available.

(*d*) When the sea water is colder than the air the visible horizon is raised and the dip is decreased; therefore the true altitude is greater than that given by the use of the ordinary dip table. When the water is warmer than the air, the horizon is depressed and the dip is increased. At such times the altitude is really less than that found from the use of the table.

The same cause, it may be mentioned here, affects the kindred matter of the visibility of objects. When the air is warmer, terrestrial objects are sighted from a greater distance and appear higher above the horizon than under ordinary conditions. When the water is warmer than the air, the distance of visibility is reduced, and terrestrial objects appear at a less altitude.

302. What has been said heretofore about the dip supposes the horizon to be free from all intervening land or other objects; but it often happens that an observation is required to be taken from a ship sailing along shore or at anchor in harbor, when the sun is over the land and the shore is nearer the ship than the visible sea horizon would be if it were unconfined; in this case the dip will be different from that of Table 14, and will be greater the nearer the ship is to that point of the shore to which the sun's image is brought down. In such case Table 15 gives the dip at different heights of the eye and at different distances of the ship from the land.

303. The dip is always to be subtracted from the observed altitude.

PARALLAX.

304. The *parallax* of a heavenly body is, in general terms, the angle between two straight lines drawn to the body from different points. But in Nautical Astronomy *geocentric parallax* is alone considered, this being the difference between the positions of a heavenly body as seen at the same instant from the center of the earth and from a point on its surface.

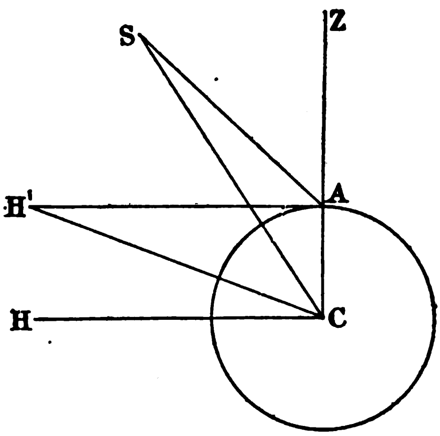

FIG. 47.

The zenith distance of a body, S (fig. 47), seen from A, on the surface of the earth, is ZAS; seen from C it is ZCS; the *parallax* is the difference of these angles, ZAS − ZCS = ASC.

Parallax in altitude is, then, the angle at the heavenly body subtended by the radius of the earth.

If the heavenly body is in the horizon as at H′, the radius, being at right angles to AH′, subtends the greatest possible angle at the star for the same distance, and this angle is called the *horizontal parallax*. The parallax is less as the bodies are farther from the earth, as will be evident from the figure.

Let par. = parallax in altitude, ASC;
Z = SAZ, the apparent zenith distance (corrected for refraction);
R = AC, the radius of the earth; and
D = CS, the distance of the object from the center of the earth.

Then, since SAC = 180° − SAZ, the triangle ASC gives:

$$\sin \text{par.} = \frac{R \sin Z}{D}.$$

If the object is in the horizon at H′, the angle AH′C is the horizontal parallax, and denoting it by H. P. the right triangle AH′C gives:

$$\sin \text{H. P.} = \frac{R}{D}.$$

Substituting this value of $\frac{R}{D}$ in the above,

$$\sin \text{par.} = \sin \text{H. P.} \sin Z.$$

If h = SAH′, the apparent altitude of the heavenly body, then $Z = 90° - h$; hence,

$$\sin \text{par.} = \sin \text{H. P.} \cos h.$$

Since par. and H. P. are always small, the sines are nearly proportional to the angles; hence,

$$\text{par.} = \text{H. P.} \cos h.$$

305. The Nautical Almanac gives the horizontal parallax of the moon, as well as of the planets Venus, Mars, Jupiter, and Saturn.

In Table 16 will be found the values of the sun's parallax for altitude intervals of 5° or 10°, while Table 20 B contains the combined values of the sun's parallax and the refraction. In Table 24 is given the parallax of the moon, combined with the refraction, at various altitudes and for various values of the horizontal parallax.

306. Parallax is always additive; combined parallax and refraction additive in the case of the moon, but subtractive for the sun.

As the correction for parallax of the moon is so large, it is essential that it be taken from the table with considerable accuracy; the corrections for index correction, semidiameter, and dip should therefore be applied first, and the "approximate altitude" thus obtained should be used as an argument in entering Table 24 for parallax and refraction.

SEMIDIAMETER.

307. The *semidiameter* of a heavenly body is half the angle subtended by the diameter of the visible disk at the eye of the observer. For the same body the semidiameter varies with the distance; thus, the difference of the sun's semidiameter at different times of the year is due to the change of the earth's distance from the sun; and similarly for the moon and the planets.

In the case of the moon, the earth's radius bears an appreciable and considerable ratio to the moon's distance from the center of the earth; hence the moon is materially nearer to an observer when in or near his zenith than when in or near his horizon, and therefore the semidiameter, besides having a menstrual change, has a semidiurnal one also.

The increase of the moon's semidiameter due to increase of altitude is called its *augmentation*. This reduction may be taken from Table 18.

The semidiameters of the sun, moon, and planets are given in their appropriate places in the Nautical Almanac.

The semidiameter is to be added to the observed altitude in case the lower limb of the body is brought into contact with the horizon, and to be subtracted in the case of the upper limb. When the artificial horizon is used, the limb of the *reflected* image is that which determines the sign of this correction, it being additive for the lower and subtractive for the upper.

EXAMPLE: May 6, 1916, the observed altitude of the sun's upper limb was 62° 10′ 40″; I. C., + 3′ 10″; height of the eye, 25 feet. Required the true altitude.

Obs. alt. ☉̄,		62° 10′ 40″	I. C.,	+ 3′ 10″
Corr.,	−	18 04		
			S. D. (Naut. Alm.),	− 15′ 53″
True alt.,		61 52 36	dip (Tab. 14),	− 4 54
			p. & r. (Tab. 20 B),	− 27
				− 21 14
			Corr.,	− 18′ 04″

EXAMPLE: The altitude of Sirius as observed with an artificial horizon was 50° 59′ 30″; I. C., − 1′ 30″. Required the true altitude.

Obs. 2 alt. ✱,		50° 59′ 30″
I. C.,	−	1 30
		2)50 58 00
Obs. alt.,		25 29 00
ref. (Tab. 20 A),	−	2 02
True alt.,		25 26 58

EXAMPLE: April 16, 1916, observed altitude of Venus 53° 26′ 10″; I. C., + 2′ 30″; height of eye, 20 feet. Required the true altitude.

Obs. alt. ✱,	53° 26′ 10″	par. (Tab. 17),	+ 0′ 06″	Hor. Par. (Naut. Alm.), 11″.4
Corr.,	− 2 30	I. C.,	+ 2 30	
	53 23 40		+ 2 36	
		dip (Tab. 14),	− 4′ 23″	
		ref. (Tab. 20 A),	− 43	
			− 5 06	
		Corr.,	− 2′ 30″	

EXAMPLE: May 6, 1916, at 13^h 24^m G. M. T., the observed altitude of the moon's lower limb was 25° 30′ 30″; I. C., −1′ 30″; height of eye, 20 feet. Required the true altitude.

Obs. alt. ☾,	25° 30′ 30″	S. D. (Naut. Alm.),	+14′ 48″	Hor. Par. (Naut. Alm.), 54′ 06″.
1st corr.,	+ 9 01	Aug. (Tab. 18),	+ 06	
Approx. alt.,	25 39 31		+14 54	
p. & r. (Tab. 24),	+ 46 45	dip. (Tab. 14),	− 4′ 23″	
True alt.,	26 26 16	I. C.,	− 1 30	
			− 5 53	
		1st corr.,	+ 9′ 01″	

Or, the following modification may be adopted:

Obs. alt. ☾,	25° 30′ 30″	S. D.,	+14′ 48″	H. P.,	3246″	log. 3.51135
1st corr.,	+ 6 59	Aug.,	+ 06	App. alt.,	25° 38′	cos 9.95504
Approx. alt.,	25 37 29		+14 54	par.,	{ 2927″ / 48′ 47″	log. 3.46639
par.,	+ 48 47	dip.,	− 4′ 23″			
True alt.,	26 26 16	ref.,	− 2 02			
		I. C.,	− 1 30			
			− 7 55			
		1st corr.,	+ 6′ 59″			

308. The corrections for dip, parallax, refraction, and semidiameter, which must be applied to the observed altitude of a star or of the sun's lower limb in order to obtain the true altitude, have been combined in Table 46, and for the moon's upper and lower limb in Table 49, and will henceforth be used in all subsequent problems. This is done in order to save the time and labor involved in referring to separate tables of these corrections.

The tabulated correction for an observed altitude of a star combines the mean refraction and the dip; and that for the observed altitude of the sun's lower limb, the mean refraction, the dip, the parallax, and the mean semidiameter, which is taken as 16′. A supplementary table, taking account of the variation of the sun's semidiameter in the different months of the year, is given in connection with the main table.

Thus, in the first example under article 324, we may, when variations from the mean state of the atmosphere (barometer 30 inches, Fahr. thermometer 50°) are left out of consideration, proceed as follows:

Measured altitude .... ☉ =			40°	04′	00″
I. C. = +				3	00
Correction from Table 46, height of eye 20 feet..	+10′ 35″		40	07	00
Supplementary table for June 21	− 0 14			10	21
True altitude			40	17	21

And, in the sixth example under article 324, with the horizontal parallax and the observed altitude corrected for index error, we may obtain the correction of the measured altitude of the moon from Table 49, as follows:

Measured altitude .... ☽ =		59°	06′	40″
I. C. = +			2	00
		59	08	40
Correction from Table 49, for height of eye, 35 feet..	7′ 58″ }		9	30
Supplementary table, for height of eye, 19 feet ..	1 32 }			
True altitude		59°	18	10

CHAPTER XI.

THE CHRONOMETER ERROR.

309. It has already been explained (art. 261, Chap. VIII) that the *error* of a chronometer is the difference between the time indicated by it and the correct standard time to which it is referred; and that the *daily rate* is the amount that it gains or loses each day. In practice, chronometer errors are usually stated with reference to Greenwich mean time. It is not required that either the error or the rate shall be zero, but in order to be enabled to determine the correct time it is essential that both rate and error be known and that the rate shall have been uniform since its last determination.

310. DETERMINING THE RATE.—Since all chronometers are subject to some variation in rate under the changeable conditions existing on shipboard, it is desirable to ascertain a new rate as often as possible. The process of obtaining a rate involves the determination of the error on two different occasions separated by an interval of time of such length as may be convenient; the change of error during this interval, divided by the number of days, gives the daily rate.

EXAMPLE: On March 10, at noon, found chronometer No. 576 to be $0^m\ 32^s.5$ fast of G. M. T.; on March 20, at noon, the same chronometer was $0^m\ 48^s.0$ fast of G. M. T. What was the rate?

Error, March $10^d\ 0^h$,	$+0^m\ 32^s.\ 5$
Error, March $20^d\ 0^h$,	$+0\ \ 48\ .\ 0$
Change in 10 days,	$+\ \ 15\ .\ 5$
Daily rate,	$+\ \ 1^s.55$

The chronometer is therefore *gaining* $1^s.55$ per day.

311. DETERMINING ERROR FROM RATE.—The error on any given day being known, together with the daily rate, to find the error on any other day it is only necessary to multiply the rate by the number of days that may have elapsed and to apply the product with proper sign to the given error.

EXAMPLE: On December 17 a chronometer is $3^m\ 27^s.5$ slow of G. M. T. and losing $0^s.47$ daily. What is the error on December 26?

Error Dec. 17,	$-3^m\ 27^s.5$	Daily rate,	$-0^s.47$
Correction,	$-\ \ \ 4\ .2$	No. days,	9
Error Dec. 26,	$-3\ \ 31\ .7$	Corr.,	$-4\ .23$

The chronometer is therefore *slow* of G. M. T. on December 26, $3^m\ 31^s.7$.

312. It is necessary to distinguish between the signs of the chronometer *correction* and of the chronometer *error*. A chronometer fast of the standard time is considered as having a *positive error*, since its readings are positive to (greater than) those of an instrument showing correct time; but the same chronometer has a *negative correction*, as the amount must be subtracted to reduce chronometer readings to correct readings.

313. Numerous methods are available for determining the error of a chronometer in port. The principal of these will be given.

BY TIME SIGNALS.

314. In nearly all of the important ports of the world a time signal is made each day at some defined instant. In many cases this consists in the dropping of a time ball—the correct instant being given telegraphically from an observatory. In a number of places where there is no time ball a signal may be received on the instruments at the telegraph offices, whereby mariners may ascertain the errors of their chronometers. Such signals are to be had in almost every port of the United States, and similar signals are being sent out from Government radio stations, so that it is now possible to find the error of the chronometer on board ships fitted with receiving instruments when lying in port and also when underway within radio distance of these stations.

The time signal may be given by a gunfire or other sound, in which case allowance must be made by the observer for the length of time necessary for the sound to travel from the point of origin to his position. Sound travels 1,090 feet per second at 32° F., and its velocity increases at the rate of 1.15 feet per second with each degree increase of temperature. If V be the velocity of sound in feet per second at the existing temperature, and D the distance in feet to be traversed, $\frac{D}{V}$ is the number of seconds to be subtracted from the chronometer reading at the instant of hearing the signal to ascertain the reading at the instant the signal was made.

This method of obtaining the chronometer error consists in taking the difference between the standard time and chronometer time at the time of observation and marking the result with appropriate sign.

EXAMPLE: A time ball drops at $5^h\ 0^m\ 0^s$, G. M. T., and the reading of a chronometer at the same moment is $4^h\ 57^m\ 52^s.5$. What is the chronometer error?

G. M. T.,		5^h	00^m	00^s
Chro. t.,		4	57	52.5
Chro. error,	−		2	07.5

That is, chronometer is *slow* $2^m\ 07^s.5$; chronometer *correction* additive.

BY TRANSITS.

315. The most accurate method of finding the chronometer correction is by means of a transit instrument well adjusted in the meridian, noting the times of transit of a star or the limbs of the sun across the threads of the instrument.

At the instant of the body's passage over the meridian wire, mark the time by the chronometer. The hour angle at the instant is 0^h; therefore the local sidereal time is equal to the right ascension of the body in the case of a star, or the local apparent time is 0^h in the case of the sun's center. By converting this sidereal or apparent time into the corresponding mean time and applying the longitude, the Greenwich mean time of transit is given. By comparing with this the time shown by chronometer the error is found.

EXAMPLE: 1916, May 9 (Ast. day), in Long. 44° 39′ E., observed the transit of Arcturus over the middle wire of the telescope, the time noted by a chronometer regulated to Greenwich mean time being $8^h\ 05^m\ 33^s.5$. Required the error.

L. S. T. (R. A. ✱).		14^h	11^m	$52^s.9$
Long.,	−	2	58	36
G. S. T.,		11	13	16.9
R. A. M. S., $9^d\ 0^h$,	−	3	07	51.8
Sid. int. from 0^h,		8	05	25.1
Reduction (Tab. 8),	−		1	19.5
G. M. T.,		8	04	05.6
Chro. t.,		8	05	33.5
Chro. fast,			1	27.9

EXAMPLE: June 25, 1916, in Long. 60° E., observed the transit of both limbs of the sun over the meridian wire of the telescope, noting the times by a chronometer. Find the error of the chronometer on G. M. T.

Transit of western limb,		8^h	04^m	$02^s.5$	Eq. t., $24^d\ 20^h$., $2^m\ 19^s.1$
Transit of eastern limb,		8	06	20.0	*Add to apparent* time.
Chro. time, loc. app. noon,		8	05	11.25	
L. A. T., loc. app. noon,		0^h	00^m	00^s	
Eq. t.,	+		2	19.1	
L. M. T., loc. app. noon,		0	02	19.1	
Long.,	−	4	00	00	
G. M. T., loc. app. noon,		8	02	19.1	
Chro. time, loc. app. noon,		8	05	11.25	
Chro. fast,			2	52.15	

BY A SINGLE ALTITUDE (TIME SIGHT).

316. The problem involved in this solution, by reason of its frequent application in determining the longitude at sea, is one of the most important ones in Nautical Astronomy. It consists in finding the hour angle from given values of the altitude, latitude, and polar distance. The hour angle thus obtained is converted by means of the longitude and equation of time in the case of the sun, or longitude and right ascension in the case of other celestial bodies, into Greenwich mean time; and this, compared with the chronometer time, gives the error.

It should be borne in mind that the most favorable position of the heavenly body for time observations is when near to the prime vertical. When exactly in the prime vertical a small error in the latitude produces no appreciable effect. Therefore, if the latitude is uncertain, good results may be obtained by observing the sun or other body when bearing east or west. If observations are made at the same or nearly the same altitude on each side of the meridian and the mean of the results is taken, various errors are eliminated of which it is otherwise impossible to take account, and a very accurate determination is thus afforded.

317. With a sextant and artificial horizon or good sea horizon, several altitudes of a body should be observed in quick succession, noting in each case the time as shown by a hack chronometer or comparing watch whose error upon the standard chronometer is known. Condensing the observation into a brief interval justifies the assumption that the altitude varies uniformly with the time. A very satisfactory method is to set the sextant in advance at definite intervals of altitude and note the time as contact is observed.

318. Correct the observed altitude for instrumental and other errors, reducing the apparent to the true altitude.

If the sun, the moon, or a planet is observed, the declination is to be taken from the Nautical Almanac for the time of the observation. If the chronometer correction is not approximately known and it is therefore impossible to determine the Greenwich

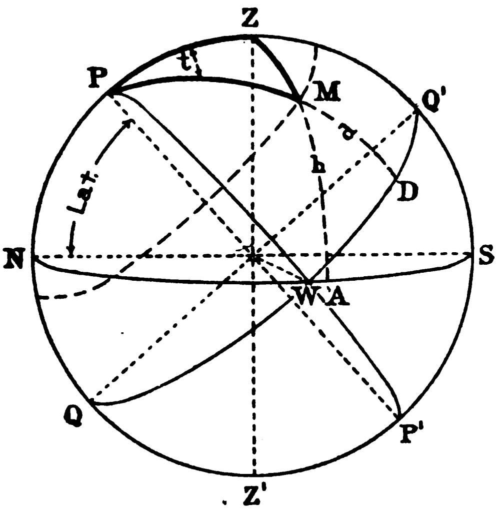

FIG. 48.

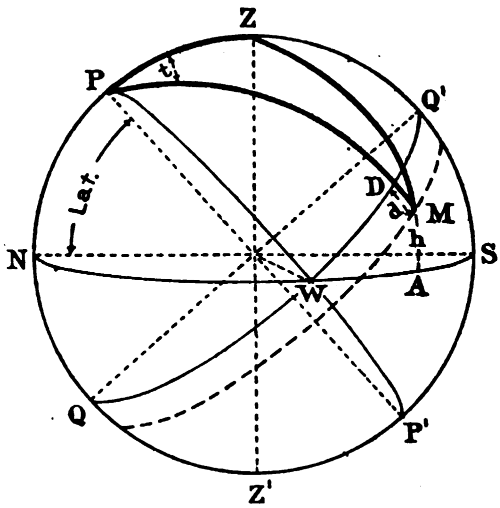

FIG. 49.

mean time of observation with a fair degree of accuracy, the first hour angle found will be an approximate one; the declination corrected by this new value of the time will produce a more exact value of the hour angle, and the operation may be repeated until a sufficiently precise value is determined.

319. In figures 48 and 49 are given:

AM $= h$, the altitude of the body M;

DM $= d$, the declination; and

Q′Z $=$ L, the latitude of the place.

In the astronomical triangle PMZ there may be found from the foregoing:

ZM $= z$, the zenith distance of the body, $= 90° - h$;

PM $=p$, the polar distance, $=90°\pm d$; and
PZ $=$co.L, the co-latitude of the place, $=90°-\text{L}$.

From these data it is required to find the angle MPZ the hour angle of the body, $=t$. This is given by the formula:

$$\sin^2 \tfrac{1}{2}\, t = \frac{\cos \frac{1}{2}\,(h+\text{L}+p)\sin \frac{1}{2}\,(\text{L}+p-h)}{\cos \text{L} \sin p}.$$

If we let $s=\frac{1}{2}\,(h+\text{L}+p)$, this becomes:

$$\sin \tfrac{1}{2}\, t = \sqrt{\sec \text{L} \operatorname{cosec} p \cos s \sin (s-h)}.$$

The polar distance is obtained by adding the declination to 90° when of different name from the latitude and subtracting it from 90° when of the same name. Like latitude and altitude, it is always positive.

If the sun is the body observed, the resulting hour angle is the local apparent time and is to be taken from the a. m. or p. m. column of Table 44 according as the altitude is observed in the forenoon or afternoon. If the moon, a star, or a planet be taken, the hour angle is always found in the p. m. column.

Local apparent time as deduced from an observation of the sun is converted to local mean time by the application of the equation of time; then, by adding the longitude if west and subtracting it if east, the Greenwich mean time is obtained.

The hour angle of any other body, added to its right ascension when it is west of the meridian at observation or subtracted therefrom when east, gives the local sidereal time, which may be reduced to Greenwich sidereal time by the application of the longitude, and thence to Greenwich mean time by methods previously explained.

A comparison of the Greenwich mean time with the chronometer time of sight gives the error of the chronometer.

Example: January 20, 1916, p. m., in Lat. 48° 41′ 00″ S., Long. 69° 03′ 00″ E., observed a series of altitudes of the sun with a sextant and artificial horizon; mean double altitude, 59° 03′ 10″, images approaching; mean of times by comparing watch, $4^h\ 40^m\ 56^s$; C—W, $7^h\ 23^m\ 25^s$; index correction, $-1'\ 30''$; approximate chronometer correction, $-0^m\ 10^s$. What was the exact chronometer error?

W. T.,		$4^h\ 40^m\ 56^s$
C—W,		7 23 25
Chro. t.,		0 04 21
App. C. C.,	−	0 10
App. G. M. T.,		0 04 11

Obs. 2 alt. ⊙		59° 03′ 10″
I. C.,	−	1 30
		2)59 01 40
⊙		29 30 50
Corr.,	+	14 43
h,		29 45 33
S. D.,	+	16′ 17″
$p.$ & $r.$,	−	1′.34″
Corr.,	+	14′ 43″

Dec. 0^h.,		20° 20′.8 S.
H. D.,	−	0′.5
G. M. T.,		$0^h.07$
Corr.,	−	0′.035
Dec.,		20° 20′ 46″ S.
$p.$,		69° 39′ 14″

Eq. t. 0^h,		$10^m\ 51^s.7$
H. D.,	+	$0^s.7$
G. M. T.,		$0^h.07$
Corr.,	+	$0^s.046$
Eq. t., $0^h\ 4^m\ 11^s$,		$10^m\ 51^s.8$
(*Add to apparent* time.)		

h	29° 45′ 33″		
L	48 41 00	sec	.18031
p	69 39 14	cosec	.02798
	2)148 05 47		
s	74 02 54	cos	9.43906
$s-h$	44 17 21	sin	9.84403
			2)19.49138
L. A. T.,	$4^h\ 30^m\ 40^s.4$	sin $\frac{1}{2}t$	9.74569

L. A. T.,		$4^h\ 30^m\ 40^s.4$
Eq. t.,	+	10 51.8
L. M. T.,		4 41 32.2
Long.,		−4 36 12.0
G. M. T.,		0 05 20.2
Chro. t.,		0 04 21.0
Chro. slow,		0 00 59.2

Since $\sin^2 \frac{1}{2}\, t =$ haversine t, the haversine table, No. 45, may be applied to the solution of the present examples, and to all problems depending upon the solution of the above formula as in article 343, by using the sum obtained by the addition of the four logarithms as log. hav. t, thus, in the following example, entering Table 45 with 9.31418, the required hour angle is at once found to be $3^h\ 36^m\ 01^s.3$.

Example: May 18, 1916, p. m., in Lat. 8° 03′ 22″ S., Long. 34° 51′ 57″ W., observed a series of altitudes of the star Arcturus, east of the meridian, using artificial horizon; mean double altitude, 60° 10′; mean watch time, $6^h\ 50^m\ 32^s$; C—W, $2^h\ 20^m\ 59^s.5$; I. C., +2′ 00″. Find the true error of the chronometer.

W. T.,	$6^h\ 50^m\ 32^s$
C—W,	2 20 59.5
Chro. t.,	9 11 31.5

Obs. 2 alt. ✱,		60° 10′ 00″
I. C.,	+	2 00
		2)60 12 00
		30 06 00
ref.,	−	1 40
h,		30 04 20

R. A. ✱,	$14^h\ 11^m\ 52^s.9$
Dec. ✱,	19° 36′ 54″ N.
p,	109° 36′ 54″

h	30° 04′ 20″		
L	8 03 22	sec	.00431
p	109 36 54	cosec	.02596
	2)147 44 36		
s	73 52 18	cos	9.44372
$s-h$	43 47 58	sin	9.84019
			2)19.31418
H. A.,	$3^h\ 36^m\ 01^s.3$ E.	sin ½ t	9.65709

R. A. ✱,	$14^h\ 11^m\ 52^s.9$
H. A.,	− 3 36 01.3
L. S. T.,	10 35 51.6
Long.,	+ 2 19 27.8
G. S. T.,	12 55 19.4
R. A. M. S., 0^h,	− 3 43 20.8
Sid. int. from 0^h,	9 11 58.6
Red. (Tab. 8),	− 1 30.4
G. M. T.,	9 10 28.2
Chro. t.,	9 11 31.5
Chro. fast,	1 03.3

BY DOUBLE ALTITUDES OR ALTITUDES ON OPPOSITE SIDES OF THE MERIDIAN.

320. Instead of relying on a single determination of the chronometer error from altitudes on one side of the meridian, it is better to observe the same body on both sides of the meridian, and, if possible, at about the same altitude. The error of the chronometer having been found from each set of sights, the mean is taken as the correct error, and this mean will probably be nearer the true error than the result from either set; the effect of the constant errors of latitude, instrument, and observer, being opposite in the two cases, will be eliminated by taking the mean.

CHAPTER XII.

LATITUDE.

BY MERIDIAN ALTITUDE.

321. The latitude of a place on the surface of the earth, being its angular distance from the equator, is measured by an arc of the meridian between the zenith and the equator, and hence is equal to the declination of the zenith; therefore, if the zenith distance of any heavenly body when on the meridian be known, together with the declination of the body, the latitude can be found.

Let figure 50 represent a projection of the celestial sphere on the plane of the meridian NZS; O, the center of the sphere; NS, the horizon; P and P′, the poles of the sphere; QOQ′, the equator; Z, the zenith of the observer. Then, by the above definition, ZQ will be the latitude of the observer; and NP, the altitude of the elevated pole, will also equal the latitude.

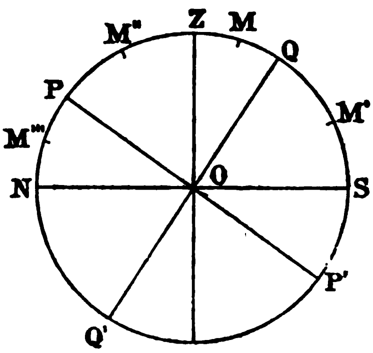

FIG. 50.

Let M be the position of a heavenly body north of the equator, but south of the zenith; $QM = d$, its declination; $MS = h$, its altitude; and $ZM = z = 90° - h$, its zenith distance.

From the figure we have:

$$QZ = QM + MZ, \text{ or}$$
$$L = d + z.$$

By attending to the names of z and d, marking the zenith distance north or south according as the zenith is north or south of the body, the above equation may be considered general for any position of the body at upper transit, as M, M′, M″.

In case the body is below the pole, as at M‴—that is, at its lower culmination—the same formula may be used by substituting $180° - d$ for d. Another solution is given in this case by observing that:

$$NP = PM''' + NM''', \text{ or}$$
$$L = p + h.$$

322. A common practice at sea is to commence observing the altitude of the sun's lower limb above the sea horizon about 10 minutes before noon, and then, by moving the tangent-screw, to follow the sun as long as it rises; as soon as the highest altitude is reached, the sun begins to fall and the lower limb will appear to *dip*. When the sun dips the reading of the limb is taken, and this is regarded as the meridian observation.

It will, however, be found more convenient, and frequently more accurate, for the observer to have his watch set for the local apparent time of the prospective noon longitude, or to know the error of the watch thereon, and to regard as the *meridian* altitude that one which is observed when the watch indicates noon. This will save time and try the patience less, for when the sun transits at a low altitude it may remain "on a stand," without appreciable decrease of altitude for several minutes after noon; moreover, this method contributes to accuracy, for when the conditions are such that the motion in altitude due to change of hour angle is a slow one, the motion therein due to change of the observer's latitude may be very material, and thus have considerable influence on the time of the sun's dipping. This error is large enough to take account of in a fast-moving vessel making a course in which there is a good deal of northing or southing.

In observing the altitude of any other heavenly body than the sun, the watch time of transit should previously be computed and the meridian altitude taken by time rather than by the dip. This is especially important with the moon, whose rapid motion in declination may introduce still another element of inaccuracy.

323. The watch time of transit for the sun, or other heavenly body, may be found by the forms given below, knowing the prospective longitude, the chronometer error, and the amount that the watch is slow of the chronometer. In this connection, article 404 describing the method of setting the watch to L. A. T. may be profitably read.

For the Sun.			*For other Bodies.*		h m s
L. A. T. noon,		$0^h\ 00^m\ 00^s$	L. S. T. transit,		(Right ascension.)
Long. (+if west),	±	______	Long. (+if west),	±	______
G. A. T.,			G. S. T.,		
Eq. t.,	±	______	R. A. M. S., 0^h,	−	______
G. M. T.,			Sid int. from 0^h,		
C. C. (sign reversed),	∓	______	Red. (Tab. 8),	−	______
Chro. time,			G. M. T.,		
C—W,	−	______	C. C. (sign reversed),	∓	______
Watch time noon,			Chro. time,		
			C—W,	−	______
			Watch time transit,		

324. From the observed altitude deduce the true altitude, and thence the true zenith distance. Mark the zenith distance North if the zenith is north of the body when on the meridian, South if the zenith is south of the body.

Take out the declination of the body from the Nautical Almanac for the time of meridian passage, having regard for its proper sign or name.

The algebraic sum of the declination and zenith distance will be the latitude. Therefore, add together the zenith distance and the declination if they are of the same name, but take their difference if of opposite names; this sum or difference will be the latitude, which will be of the same name as the greater.

EXAMPLE: At sea, June 21, 1916, in Long. 60° W., the observed meridian altitude of the sun's lower limb was 40° 4′; sun bearing south; I. C., +3′ 0″; height of the eye, 20 feet; required the latitude.

Obs. alt.,	40° 04′ 00″	(Tab. 46),	+10′ 21″	Dec.,	23° 27′.1 N.	G. A. T.,	$4^h\ 00^m\ 00^s$
Corr.,	+ 13 21	I. C.,	+ 3 00			Eq. t.,	1 31 .7
				H. D.,	0 .0		
h,	40 17 21	Corr.,	+13′ 21″			G. M. T.,	4 01 31 .7
z,	49° 42′ 39″ N.					Eq. t., 4^h	$1^m\ 31^s.7$
d,	23 27 06 N.					(Add to app. time.)	
L,	73 09 45 N.						

EXAMPLE: At sea, April 14, 1916, in Long. 140° E., the observed meridian altitude of the sun's lower limb was 81° 15′ 30″; sun bearing north; I. C., −2′ 30″; height of the eye, 20 feet.

Obs. alt.,	81° 15′ 30″	(Tab. 46),	+11′ 30″	Dec., $13^d\ 14^h$,	9° 14′.4 N.	G. A. T.,	$13^d\ 14^h\ 40^m\ 00^s$	Eq. t., $13^d\ 14^h$,	$0^m\ 26^s.6$
Corr.,	+ 9 00	I. C.,	− 2 30			Eq. t., +	26 .2	Corr.,	− .4
				H. D.,	+ 0′.9				
h,	81 24 30	Corr.,	+ 9′ 00″	G. M. T.,	$0^h.67$	G. M. T.,	13 14 40 26 .2	Eq. t., $13^d\ 14^h\ 40^m$,	0 26 .2
z,	8° 35′ 30″ S.			Corr.,	+ 0′.603			H. D.,	− $0^s.6$
d,	9 15 00 N.							Int.,	$0^h.7$
				Dec.,	9° 15′ N.				
L,	0 39 30 N.							Corr.,	− $0^s.42$

EXAMPLE: At sea, May 15, 1916, in Long. 0°, the observed meridian altitude of the sun's lower limb was 30° 13′ 10″; sun bearing north; I. C., +1′ 30″; height of the eye, 15 feet.

Obs. alt.,	30° 13′ 10″	(Tab. 46),	+10′ 32″	Dec., $14^d\ 22^h$,	18° 50′.2 N.	G. A. T.,	$0^h\ 00^m\ 00^s$
Corr.,	+ 12 02	I. C.,	+ 1 30			Eq. t., −	3 47 .5
				H. D.,	+ 0′.6		
h,	30 25 12	Corr.,	+12 02	G. M. T.,	$1^h.94$	G. M. T.,	$14^d\ 23^h\ 56^m\ 12^s.5$
z,	59° 34′ 48″ S.			Corr.,	+ 1′.16		
d,	18 51 24 N.						
				Dec.,	18° 51′.4 N.		
L,	40 43 24 S.						

Example: January 1, 1916, the observed meridian altitude of Sirius was 53° 23′ 40″, bearing south; I. C., +5′ 0″; height of the eye, 17 feet.

Obs. alt.,	53° 23′ 40″	(Tab. 46) −4′ 45″		Dec. ✱, 16° 36′ 00″ S.
Corr.,	+ 15	I. C. +5 00		
h,	53 23 55	Corr. +0′ 15″		
z,	36° 36′ 05″ N.			
d,	16 36 00 S.			
L,	20 00 05 N.			

Example: June 13, 1916, in Long. 65° W., and in a high northern latitude, the meridian altitude of the sun's lower limb was 8° 16′ 10″ below the pole; height of the eye, 20 feet; I. C., 0′ 00″.
Greenwich apparent time of lower culmination, June 13, $16^h\ 20^m$ (=Long.+12^h).

Obs. alt.,	8° 16′ 10″	(Tab. 46),	+ 5′ 11″	G. A. T.,	$16^h\ 20^m\ 00^s$
Corr.,	5 11			Eq. t.,	− 04. 3
h,	8 21 21	Dec. 16^h,	23° 15.′1 N.	G. M. T.,	$16^h\ 19^m\ 55^s.7$
z,	81° 38′ 39″ S.	H. D.,	+ 0″.1		
180°−d,	156 44 52 N.	G. M. T.,	$0^h.33$		
L,	75 06 13 N.	Corr.,	+ 0″.03		
Alternative method.		Dec.,	23° 15′ 08″ N.		
h,	8° 21′ 21″				
p,	66 44 52	p,	66° 44′ 52″		
L,	75 06 13 N.	180°−d,	156° 44′ 52″ N.		

Example: July 10, 1916, in Long. 80° W., the observed meridian altitude of the moon's upper limb was 59° 6′ 40″, bearing north; I. C., +2′ 0″; height of the eye, 19 feet.

Obs. alt.,	59° 06′ 40″	(Tab. 49),	+ 9′ 30″	G. M. T., of Gr. transit	$7^h\ 40^m$
Corr.,	+ 11 30	I. C.,	+ 2 00	Corr. for Long. (Tab. 11),	+ 13
h,	59 18 10	Corr.,	+ 11′ 30″	L. M. T. local transit,	7 53
				Long.,	+ 5 20
z,	30 41 50 S.	Hor. Par.,	59′ 12″		
d,	22 40 42 S.			G. M. T., local transit,	$13^h\ 13^m$
L,	53 22 32 S.	Dec. 12^h,	22° 30′.4 S.	H. D.,	− 8.′5
		Corr.,	− 10 .3	G. M. T.,	$1^h.22$
		Dec.,	22° 40′.7 S.	Corr.,	− 10′.3

Example: At sea, September 16, 1916, in Long. 75° E., the observed meridian altitude of Jupiter was 51° 25′ 24″, bearing north; I. C., +3′ 0″; height of the eye, 16 feet.

Obs. alt.,	51° 25′ 24″	(Tab. 46),	− 4′ 42″	G. M. T., Gr. transit,	$14^h\ 28^m$
Corr.,	− 1 42	I. C.,	+ 3 00	Corr. for Long.,	+ 1
h,	51 23 42	Corr.,	− 1′ 42″	L. M. T., of local transit,	14 29
				Long.,	− 5 00
z,	38 36 18 S.				
d,	11 38 54 N.			G. M. T. of local transit,	9 29
L,	26 57 24 S.	Dec. 0^h,	11° 39′.5 N.	H. D.,	− 4″
		Corr.,	− .6	G. M. T.,	$9^h.48$
		Dec.,	11° 38′.9 N.	Corr.,	−37″=.6′

325. Constant.—In working a meridian altitude, especially the daily noon observation of the sun, it is frequently a convenience to arrange the terms so that all computation, excepting the application of the observed altitude, is completed beforehand; then the ship's latitude will be known immediately after the sight has been taken, it being necessary only to add or subtract the altitude. (See art. 323.)

It is assumed that the noon longitude will be sufficiently accurately known in advance to enable the navigator to correct the declination; also the approximate meridian altitude to correct the parallax and refraction; if the latter is not known, it may readily be found from the declination and approximate latitude.

Generally speaking,

$$\begin{aligned}\text{Lat.} &= \text{Zenith distance} + \text{Dec.},\\ &= 90° - \text{True alt.} + \text{Dec.},\\ &= 90° - (\text{Obs. alt.} + \text{Corr.}) + \text{Dec.},\\ &= (90° + \text{Dec.} - \text{Corr.}) - \text{Obs. alt.},\end{aligned}$$

in which the quantity (90° + Dec. − Corr.) may be termed a *Constant* for the meridian altitude of the day, as it remains the same regardless of what the observed altitude may prove to be. The constant having been worked up before the observation is made, the latitude will be known as soon as the observed altitude is applied.

To avoid the confusion that might arise from the necessity of combining the terms *algebraically* according to their different names, it may be convenient to divide the problem into four cases and lay down rules for the *arithmetical* combination of the terms, disregarding their respective names as follows:

Case I. Lat. and Dec. same name, Lat. greater, + 90° + Dec. − Corr. − Obs. alt.
Case II. Lat. and Dec. same name, Dec. greater, − 90° + Dec. + Corr. + Obs. alt.
Case III. Lat. and Dec. opposite names, + 90° − Dec. − Corr. − Obs. alt.
Case IV. Lat. and Dec. same name, lower transit, + 90° − Dec. + Corr. + Obs. alt.

The correctness of such an arrangement will become readily apparent from an inspection of figure 50. The assumption has been made that the correction to the observed altitude is positive; when this is not true the sign of the correction must be reversed.

As examples of this method, the first, second, third, and fifth of the examples previously given illustrating the meridian altitude will be worked, using the constant; the details by which Corr. and Dec. are obtained are omitted, being the same as in the originals.

	1st Example. *Case I.*	2d Example. *Case II.*	3d Example. *Case III.*	5th Example. *Case IV.*
	+ 90° 00′ 00″	−90° 00′ 00″	+90° 00′ 00″	+90° 00′ 00″
Dec.,	+ 23 27 06	+ 9 15 00	−18 51 24	−23 15 08
Corr.,	− 13 21	+ 9 00	− 12 02	+ 5 11
Constant,	+113 13 45	−80 36 00	+70 56 34	+66 50 03
Obs. alt.,	− 40 04 00	+81 15 30	−30 13 10	+ 8 16 10
Lat.,	73 09 45 (N.)	0 39 30 (N.)	40 43 24 (S.)	75 06 13 (N.)

BY REDUCTION TO THE MERIDIAN.

326. Should the meridian observation be lost, owing to clouds or for other reason, altitudes may be taken near the meridian and the times noted by a watch compared with the chronometer, from which, knowing the longitude, the hour angle may be deduced.

If the observations are within 26^m from the meridian, before or after, the correction to be applied to the observed altitude to reduce it to the meridian altitude may be found by inspection of Tables 26 and 27. Table 26 contains the variation of the altitude for one minute from the meridian, expressed in seconds and tenths of a second. Table 27 contains the product obtained by multiplying the square of the minutes and seconds by the change of altitude in one minute.

Let a = change of altitude (in seconds of arc) in one minute from the meridian:
H = meridian altitude;
h = corrected altitude at observation; and
t = interval from meridian passage.

The value of the reduction to the meridian altitude of each altitude is found by the formula:

$$H = h + at^2,$$

a being found in Table 26, and at^2 in Table 27; hence the following rule:

Find the hour angle of the body in minutes and seconds of time. Take from Table 26 the value of a corresponding to the declination and the latitude. Take from Table 27 the value of at^2 corresponding to the a thus found and to the interval, in minutes and seconds, from meridian passage. This quantity will represent the amount necessary to reduce the corrected altitude at the time of observation to the corrected altitude at the meridian passage; it is always additive when the body is near upper transit, and always to be subtracted when near lower transit.

If the mean of a number of sights is to be taken, determine each reduction separately, take the mean of all the reductions, and apply it to the mean of the altitudes;

it is incorrect, in such a case, to take the mean of the times and work the sight with this single value of *t*. The differences of altitude being small, the parallax and refraction will be sensibly the same for all, and one computation of the correction to the observed altitude will suffice.

Knowing the meridian altitude, the latitude is to be found as previously explained.

327. When several sights are taken, the most expeditious method of calculating will be to find first the watch time of transit, and thence obtain the hour angle of each observation by comparing the watch time of observation. The watch time of transit may be found as already explained (art. 323) for computing that quantity as a guide in taking the meridian altitude, but the hour angle thus obtained is subject to a correction. The difference between watch time of transit and watch time of observation gives the watch time—that is, the mean time—elapsing between transit and observation. A fixed star covers in that time an angle corresponding to the sidereal and not to the mean time interval, and a reduction should be made accordingly to give its true hour angle at the instant of observation. A planet's hour angle should be corrected in the same way (for we may disregard its very small change in right ascension). The correction may be entirely neglected in the case of the sun, as the difference between mean and apparent time intervals is immaterial. The reduction of the hour angle in the case of the moon becomes rather cumbersome, so much so that it is better to find the hour angle of this body by the more usual method of converting watch time to G. M. T., and thence to L. S. T., and finding the difference between the latter and the R. A.; an additional reason for this is that the G. M. T. of observation must be known exactly, with the moon, for the correction of the declination (art. 330).

328. Table 26 includes values of the latitude up to 60°, and those of the declination up to 63°, thus taking in all frequented waters of the globe and all heavenly bodies that the navigator is likely to employ. No values of *a* are given when the altitudes are above 86° or below 6°, as the method of reduction to the meridian is not accurate when the body transits very near the zenith, and the altitudes themselves are questionable when very low. In case it is desired to find the change of altitude in one minute from noon for conditions not given in the tables, it may be computed by the formula:

$$a = \frac{1''.9635 \cos L \cos d}{\sin (L - d)}.$$

In working sights by this method where great accuracy is required, as in determining latitudes on shore for surveying purposes, it is well to compute the *a* rather than to take it from the table, as one is thus enabled to employ the value as found to the second decimal place.

Due regard must be paid to the names of the declination and latitude in working this formula; if they are of opposite names, the declination is negative, and L and *d* should be added together to obtain L—*d*.

329. Table 27 contains values of at^2 up to the limits within which the method is considered to apply with a fair degree of accuracy. It must not be understood that the plan of reduction to the meridian is not available for wider limits, but it would seem preferable to employ the ϕ' ϕ'' formula, described hereafter, when the hour angle falls beyond that for which the table is computed. On the other hand, the reduction is not exact in all cases covered by the table; while sufficiently so for sea navigation, the limits given are far too wide for the precise determinations required in surveying, where the aim should be to observe bodies under such conditions that the total reduction at^2 shall not exceed 1′.

330. It should be kept clearly in mind when employing the method of reduction to the meridian that the resulting latitude is that of the ship at the instant of observation, and to bring it up to noon the run must be applied. The declination should properly be corrected for the instant of observation; with the sun or a planet, it is sufficiently accurate to use the declination at meridian passage, unless the interval from the meridian be quite large; but the moon's declination changes so rapidly that the exact time of observation must be used in its correction when working with this body.

EXAMPLE: In latitude 47° S., having previously worked up the constant for meridian altitude, 78° 42′ 10″, observed altitude of sun near meridian, 31° 11′ 50″; Dec. 11° N.; watch time, $11^h\ 40^m\ 21^s$, watch fast of L. A. T., 7^s. Find the latitude.

Watch time,	11^h 40^m 21^s	Obs. alt.,	31° 11′ 50″	a (Tab. 26),	1″.6
Watch fast,	07	at^2, +	10 24		
L. A. T.,	11 40 14	Mer. alt.,	31 22 14	at^2 (Tab. 27),	1″.0 = 6′ 30″
		Constant,	78 42 10		.6 = 3 54
t,	19^m 46^s	Lat.,	47 19 56 S.		1 .6 = 10 24

EXAMPLE: At sea, July 12, 1916, in Lat. 50° N., Long. 40° W., observed circum-meridian altitude of the sun's lower limb, 61° 48′ 30″, the time by a chronometer regulated to Greenwich mean time being $2^h\ 41^m\ 39^s$; chro. corr., $-2^m\ 30^s$ I. C., −3′ 0″; height of the eye, 15 feet. Find the latitude.

Chro. t.,	2^h 41^m 39^s	☉	61° 48′ 30″	Dec. 2^h,	21° 58′.9 N.	Eq. t. 2^h.,	5^m 24^s.1
C. C.,	− 2 30	Corr.,	+ 8 31	H. D.,	− 0′.4	H. D.,	+ 0^s.3
G. M. T.,	2 39 09	h,	61 57 01	G. M. T.,	0^h.65	G. M. T.,	0^h.65
Eq. t.,	− 5 24.3	(Tab. 46),	+ 11′ 31″	Corr.,	− 0′.26	Corr.,	+ 0^s.195
G. A. T.,	2 33 44.7	I. C.,	− 3 00	Dec.,	21° 58′ 38″N.	Eq. t.,	5^m 24^s.3
Long.,	− 2 40 00.0	Corr.,	+ 8′ 31″			(*Subtract* from *mean* time.)	
L. A. T.,	11 53 44.7						
t,	6 15.3						

h,	61° 57′ 01″	a (Tab. 26),	2″.5
at^2, +	1 38	at^2 (Tab. 27),	2″.0 = 1′ 18″
H,	61 58 39		0 .5 = 0 20
z,	28 01 21 N.		2 .5 = 1 38
d,	21 58 38 N.		
L,	49 59 59 N.		

EXAMPLE: May 31, 1916, in Lat. 30° 15′ N., Long. $5^h\ 25^m\ 42^s$ W., about 9 p. m., observed with a sextant and artificial horizon a series of altitudes of Spica; mean observed double altitude 98° 06′ 34″; noted times as enumerated below by a watch compared with a chronometer which was $2^m\ 33^s$ fast of G. M. T.; C−W, $5^h\ 29^m\ 40^s$; I. C., −3′ 00″. Find the latitude.

R. A. ✳ (L. S. T. transit),	13^h 20^m 48^s.9	Mean 2 alt. ✳,	98° 06′ 34″	R. A. ✳,	13^h 20^m 48^s.9
Long.,	+ 5 25 42	I. C.,	− 3 00	Dec.,	10° 43′ 42″ S.
G. S. T.,	18 46 30.9		2)98 03 34	a (Tab. 26),	2″.5
R. A. M. S. Gr. 0^h,	4 34 36.1		49 01 47		
Sid. int. from 0^h,	14 11 54.8	ref.,	− 50		
Red. (Tab. 8),	− 2 19.7	h,	49 00 57		
G. M. T.,	14 09 35.1				
C. C. (sign reversed),	+ 2 33				
Chro. time transit,	14 12 08.1				
C−W,	− 5 29 40				
Watch time transit,	8 42 28				

Watch times.	Intervals from transit. Mean time.	Sid. time.	at^2 (Tab. 27). 2.0	0.5	2.5
8^h 33^m 05^s.0	− 9^m 23^s.0	− 9^m 24^s	2′ 56″	0′ 44″	3′ 40″
35 06.5	7 21.5	7 23	1 49	0 27	2 16
37 54.0	4 34.0	4 35	0 42	0 10	0 52
40 37.0	1 51.0	1 51	0 07	0 02	0 09
42 54.5	+ 0 26.5	+ 0 27	0 00	0 00	0 00
45 32.5	3 04.5	3 05	0 19	0 04	0 23
47 33.0	5 05.0	5 06	0 52	0 13	1 05
49 20.0	6 52.0	6 53	1 35	0 23	1 58
52 59.5	10 31.5	10 33	3 42	0 55	4 37
					9)15 00
					1 40

h,	49° 00′ 57″
at^2, +	1 40
H,	49 02 37
z,	40 57 23 N.
d,	10 43 42 S.
L,	30 13 41 N

Example: August 6, 1916, Lat. 59° S., Long. 175° 27′ E., during evening twilight, observed an altitude of Achernar, near lower transit, 26° 52′; watch time, $4^h\ 31^m\ 12^s$; C−W, $0^h\ 18^m\ 07^s$; chro. fast of G. M. T., $12^m\ 42^s$; I. C., +1′ 20″; height of eye, 24 ft. Find hour angle by both methods; thence the latitude.

R. A. * + 12^h / L. S. T. lower trans.		$13^h\ 34^m\ 38^s.4$
Long.,	−	11 41 48
G. S. T.,		1 52 50.4
R. A. M. S. Gr. $5^d\ 0^h$,	−	8 54 48.9
Sid. int.,		16 58 01.5
Red. (Tab. 8),	−	2 46.8
G. M. T.,		16 55 14.7
C. C. (sign reversed),	+	12 42
Chro. time,		5 07 56.7
C−W,	−	0 18 07
Watch time transit,		4 49 49.7
Watch time obs.,		4 31 12
t Mean time,		18 37.7
t Sid. time,		18 40.8

Watch time,		$4^h\ 31^m\ 12^s$
C—W.	+	0 18 07
Chro. t.,		4 49 19
C. C.,	−	12 42
G. M. T. 5^d		16 36 37
R. A. M. S. Gr. $5^d\ 0^h$,	+	8 54 48.9
Red. (Tab. 9),	+	2 43.7
G. S. T.,		1 34 09.6
Long.,	+	11 41 48
L. S. T.,		13 15 57.6
R. A. * $+12^h$		13 34 38.4
t,		18 40.8

Obs. alt. *,		26° 52′ 00″
Corr.,	−	5 23
h,		26° 46′ 37″
at^2,	−	3 29
H,		26 43 08
p,		32 20 48
L,		59 03 56 S.

(Tab. 46),	−6′ 43″
I. C.,	+1 20
Corr.,	5′ 23″

R. A. *,	$1^h\ 34^m\ 38^s.4$
Dec.,	57° 39′ 12″ S.
p,	32° 20′ 48″
a (Tab. 26),	0″.6
at^2 (Tab. 27),	3′ 29″

331. Advantages are gained in working out *meridian altitudes* and *reductions to the meridian*, in finding the *constant* for a meridian altitude or a reduction to the meridian, and in predicting the approximate altitude of a body to be observed on or near the meridian, by projecting, in a quickly and roughly drawn diagram on the plane of the meridian of the observer, the known data entering into the problem. The diagram or figure will show at once how to combine the data to find the required result, and its use tends greatly to accuracy. It is only necessary to know the meaning of the terms already defined and to remember the single principle *that the latitude of a place is equal to the declination of its zenith.*

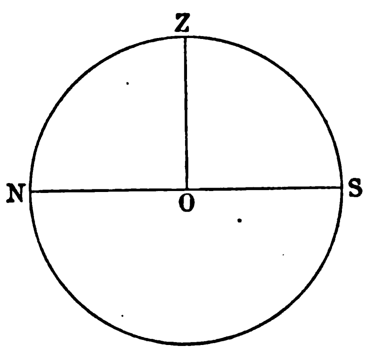

Fig. 51.

In every case draw a circle (a rough approximation will do) *to represent the plane of the meridian*, as in figure 51. The center O is the position of the observer. Draw a horizontal line through O, marking its intersection with the circumference on the right-hand side S, and on the left-hand side N. Erect a perpendicular to this line at O, and mark its intersection with the circumference Z. The line NS is the horizon; Z is the zenith. The arc ZS is that portion of the meridian between the zenith and the south point of the horizon; the arc ZN is that portion of the meridian between the zenith and the north point of the horizon. If the meridian altitude of a body is known (i. e., its altitude above the horizon on the meridian), and if it is known whether it bears to the southward or to the northward, its position can be projected at once on the figure. Having the position of the heavenly body on the meridian and knowing the declination of the body, it is evident where to draw in the projection of the equator. Having the projection of the equator, the angular distance between the equator and the zenith (i. e., the declination of the zenith) is the latitude.

Thus in figure 52, supposing the meridian altitude of any heavenly body, M, has been observed, and that at the time of observation it was bearing south; also that the declination, d, of the body was south. It is known that the true altitude, h, = observed altitude ± altitude corr. Since the body bears south, if the true altitude is h, the position of the body, M, can be located by laying off the arc SM = h, or by drawing OM so that the angle SOM = h. This gives the position of the heavenly body on the meridian. Since this body is south of the equator by the amount of the declination, the position of the equator may be drawn by laying off the angle MOQ = d. OQ is the projection of the equator, and the arc ZQ (or the angle ZOQ), being the *declination of the zenith*, is equal to the latitude. The formula for finding the latitude may be written by inspection of the figure:

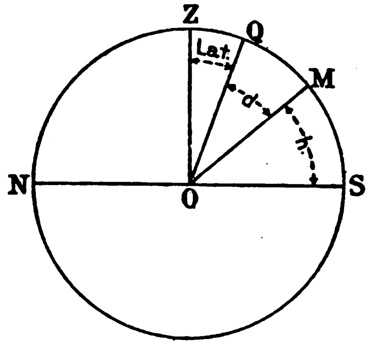

FIG. 52.

$$L = 90° - (h + d) = 90° - h - d. \qquad (1)$$

Since h = obs. alt. ± corr.,

$$L = 90° - \text{obs. alt.} \pm \text{corr.} - d. \qquad (2)$$

By a similar process formulæ may be written for determining the *approximate altitude* of the heavenly body when on the meridian and for getting a noon *constant*. The former is necessary to get the altitude correction before taking the sight; the latter, so that the latitude may be obtained as soon as the altitude is read from the sextant. In these cases the D. R. latitude and longitude, which have to be worked out in advance for noon, are used. The longitude is used to get the correction to be applied to the equation of time to get the G. M. T. of local apparent noon in order to get the correct declination at Local Apparent Noon at the noon position. Knowing the approximate latitude and the declination, they are projected on the figure in this way. If the latitude is north, the zenith is to the northward of the equator by the amount of the latitude, and to get the position of the equator lay off the angle ZOQ = Lat. If the latitude were south, the equator would of course be on the north side of the zenith by the amount of the latitude, and OQ would be on the north side of the circle. Having the position of the equator, draw in the position of the heavenly body by laying it off to the north side or to the south side of the equator according to the amount and direction of its declination. The angle between the horizon and the heavenly body will be the altitude of the body. This is the usual method of plotting, and all that has to be done is to lay the angles off on the proper sides, marking them appropriately, and then write down the formulæ. Suppose it is required to find the approximate noon altitude. An inspection of the figure shows that

$$\text{approx. } h = 90° - (L + d) \text{ where L is the D. R. Lat.} \qquad (3)$$

Suppose it is required to find the constant (K) for a meridian altitude. It is seen from the figure that

$$L = 90° - h - d = 90° - \text{obs. alt.} \pm \text{corr.} - d$$
$$= K - \text{obs. alt.}$$

or

$$K = 90° \pm \text{corr.} - d. \qquad (4)$$

In the same way any combination may be plotted, and the correct formulæ may be written out at once. Suppose on a certain day it is found that at noon the position will be approximately Lat. 10° S., Long. 30° 15′ W., and that the declination of the sun at noon, corrected for G. M. T. of local apparent noon at the noon position, is 20° 30′ S., and it is desired to find the approximate noon altitude and obtain the constant, K. Draw the circle representing the plane of the meridian (see fig. 53), draw NS representing the horizon, and OZ representing the line to the zenith. Since the approximate latitude is 10° S, the equator must be 10° north of the zenith, and OQ is drawn to the north of Z so that the angle ZOQ = 10°. OQ is then the projection of the equator. The body being 20° 30′ south of the equator, lay off OM so that the angle QOM = 20° 30′. SOM will be the approximate altitude, and the formula for it is

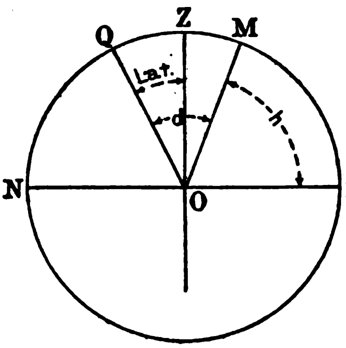

FIG. 53.

$$\text{approx. } h = 90° + L - d, \qquad (5)$$

it is also seen that

$$L = h + d - 90° = \text{obs. alt.} \pm \text{corr.} + d - 90° = K + \text{obs. alt.}$$

or

$$K = \pm \text{corr.} + d - 90°.$$

If, instead of the formulæ for a meridian altitude, the formulæ for a reduction to the meridian are required, there is no change in the figure or the method. The altitude observed before or after noon is corrected to make it the noon altitude by the formula $h = h' + at^2$, where h is the noon altitude, h' the altitude observed t minutes before or after noon, and a the rate of change of altitude near noon. So that in the case shown in figure 53

$$L = h + d - 90° = h' + at^2 + d - 90° = \text{obs. alt.} \pm \text{corr.} + at^2 + d - 90° = K + \text{obs. alt.} \qquad (6)$$

or

$$K = \pm \text{corr.} + at^2 + d - 90°.$$

The formula for the approximate value of h, as shown in (5), is used for getting the altitude correction in this case, as the slight difference in altitude makes no change in the correction.

The formula for latitude, given in equation (6), is the formula for the latitude at noon at the point where the observation was taken. But a ship steaming on a course does not remain at that point, and what is desired is the correct latitude of the ship's position at noon. If L′ represents the latitude of the place where the observation was taken, and L the latitude of the place where the ship is at noon, then $L = L' \pm \Delta L$, where ΔL is the change in latitude from the time of observation until noon. This is taken from the Traverse Tables. But from equation (6) it is seen that $L' = \text{obs. alt.} \pm \text{corr.} + at^2 + d - 90°$

$$\therefore L = L' \pm \Delta L = \text{obs. alt.} \pm \text{corr.} + at^2 + d - 90° \pm \Delta L.$$
$$= K + \text{obs. alt.}$$

or

$$K = \pm \text{corr.} + at^2 + d - 90° \pm \Delta L.$$

BY A SINGLE ALTITUDE AT A GIVEN TIME.

332. The problem is: Given the hour angle, declination, and altitude; to find the latitude. The solution is accomplished by letting fall, in the usual astronomical triangle, a perpendicular from the body to the meridian, and considering separately the distances on the meridian, from the pole and zenith, respectively, to the point of intersection of of the perpendicular; the sum or difference of these distances is the co-latitude.

The following group of equations, in which l represents the length of the perpendicular let fall from the celestial body upon the meridian, and in which ϕ' and ϕ'' represent respectively the zenith distance and the declination of the point marking the intersection of the perpendicular with the meridian, is quite generally applicable to the solution of this problem:

$$\sin l = \cos d \sin t$$
$$\sin \phi'' = \sin d \sec l$$
$$\cos \phi' = \sin h \sec l$$

Nevertheless, the usual procedure practiced by navigators and known among them as the $\phi' \phi''$ method, is in accordance with another group of equations, as follows:

$$\tan \phi'' = \tan d \sec t$$
$$\cos \phi' = \sin h \sin \phi'' \operatorname{cosec} d$$
$$\text{Lat} = \phi' + \phi''$$

According to these, the solution is impracticable when the declination is 0° as well as when the hour angle is 6^h; and, in fact, it is commonly advised that this observation should be limited to conditions where the celestial body is within three hours of meridian passage and where it is not more than 45° from the meridian in azimuth; also where the declination is at least 3°.

The terms ϕ' and ϕ'' will have different directions of application according to the position of the body relative to the observer. From a knowledge of the approximate latitude, the method of combining them will usually be apparent; it is better, however, to have a definite plan for so doing, and this may be based upon the following rule:

Mark ϕ'' north or south, according to the name of the declination; mark ϕ' north or south, according to the name of the zenith distance, it being *north* if the body bears south and east or south and west, and *south* if the body bears north and east or north and west. Then combine ϕ'' and ϕ' according to their names; the result will be the latitude, except in the case of bodies near lower transit, when $180° - \phi''$ must be substituted for ϕ'' to obtain the latitude.

It may readily be noted that if we substitute ϕ'' for declination and ϕ' for zenith distance, the problem takes the form of a meridian altitude; indeed, the method resolves itself into the finding of the zenith distance and declination of that point on the meridian at which the latter is intersected by a perpendicular let fall from the observed body.

The time should be noted at the instant of observation, from which is found the local time, and thence the hour angle of the celestial object.

If the sun is observed, the hour angle is the L. A. T. in the case of a p. m. sight, or 12^h − L. A. T. for an a. m. sight. If any other body, the hour angle may be found as hitherto explained.

EXAMPLE: June 7, 1916, in Lat. 30° 25′ N., Long. 81° 25′ 30″ W., by account; chro. time, $6^h 22^m 52^s$; obs. ⊙ 75° 13′, bearing south and west; I. C., −3′ 00″; height of the eye, 25 feet; chro. corr. $-2^m 36^s$. Find the latitude.

Chro. t.,	$6^h 22^m 52^s$	Obs. alt. ⊙,	75° 13′ 00″	Eq. t., 6^h,	$1^m 20^s.4$	Dec., 6^h,	22° 46′.6 N.
C. C.,	− 2 36	Corr.,	+ 7 39	Corr.,	− .2	Corr.,	+ .07
G. M. T.,	6 20 16	h,	75 20 39	Eq. t.,	1 20.2	Dec.,	22° 46′ 40″ N.
Eq. t.,	+ 1 20						
		(Tab. 46),	+ 10′ 39″	H. D.,	− $0^s.5$	H. D.,	+ 0′.2
G. A. T.,	6 21 36	I. C.,	− 3 00	G. M. T.,	$0^h.3$	G. M. T.,	$0^h.33$
Long.,	− 5 25 42						
		Corr.,	+ 7′ 39″	Corr.,	− $0^s.15$	Corr.,	0′.066
L. A. T. = t,	$0^h 55^m 54^s$ W. / 13° 58′ 30″			(*Add* to *mean* time.)			

t,	13° 58′ 30″		sec	.01305		
d,	22 46 40		tan	9.62315	cosec	.41211
h,	75 20 39				sin	9.98563
ϕ'',	23 23 55	N.	tan	9.63620	sin	9.59893
ϕ',	7 05 00	N.			cos	9.99667
Lat.,	30 28 55	N.				

EXAMPLE: October 10, 1916, p. m., in Lat. 6° 20′ S. by account, Long. 30° 21′ 30″ W.; chro. time, $12^h 45^m 10^s$; observed altitude of moon's upper limb, 70° 15′ 30″, bearing north and east; I. C., −3′ 00″; height of eye, 26 feet; chro. fast of G. M. T., $1^m 37^s.5$. Required the latitude.

Chro. t.,	$12^h 45^m 10^s$	Obs. alt. ☾,	70° 15′ 30″	R. A. ☾ (12^h),	$0^h 42^m 16^s$	Dec. (12^h),	9° 52′.9 N.
C. C.,	− 1 37.5	Corr.,	− 4 27	Corr.,	+ 1 32	Corr.,	+ 10.1
G. M. T.,	12 43 32.5	h,	70 11 03	R. A.,	$0^h 43^m 48^s$	Dec.,	10° 03′ N.
R. A. M. S.,	+13 15 01.4						
Red. (Tab. 9),	+ 2 05.4	(Tab. 49),	− 1′ 27″	H. D.,	+ $128^s.5$	H. D.,	+ 14′.05
		I. C.,	− 3′ 00″	G. M. T.,	$0^h.72$	G. M. T.,	$0^h.72$
G. S. T.,	2 00 39.3						
R. A. ☾,	− 0 43 48.0	Corr.,	− 4′ 27″	Corr.,	+ 92″.5	Corr.,	+ 10′.11
H. A. from Gr.,	1 16 51.3 W.						
Long.,	2 01 26.0 W.						
t,	$0^h 44^m 34^s.7$ E. / 11° 08′ 40″.5					Hor. Par.,	58′ 18″

t,	11°	08′	40″		sec	.00827		
d,	10	03	00		tan	9.24853	cosec	.75819
h,	70	11	03				sin	9.97349
ϕ'',	10	14	21	N.	tan	9.25680	sin	9.24983
ϕ',	16	36	00	S.			cos	9.98151
Lat.	6	21	39	S.				

EXAMPLE: August 6, 1916, p. m., in Lat. 52° 59′ S. by D. R., Long. 146° 32′ E., observed altitude of Achernar, near lower transit, 24° 01′ 20″ bearing south and east; watch time, 6^h 48^m 22^s; C—W, 2^h 13^m 33^s; chro. corr. on G. M. T., + 1^m 57^s; height of eye, 18 feet; I. C. +1′ 00″. Find the latitude.

Watch time,		6^h	48^m	22^s	Obs. alt. ✳,	24°	01′	20″	R. A. ✳,	1^h 34^m 38^s.4
C—W,	+	2	13	33	Corr.,	−	5	19		
									Dec.,	57° 39′ 12″ S.
Chro. t.,		9	01	55	h,	23	56	01		
C. C.,	+		1	57						
					(Tab. 46),	−	6′	19″		
G. M. T. 5^d,		21	03	52	I. C.,	+	1	00		
R. A. M. S.,	+	8	54	48.9						
Red. (Tab. 9),	+		3	27.6	Corr.,	−	5′	19″		
G. S. T.,		6	02	08.5						
R. A. ✳,		1	34	38.4						
H. A. from Gr.,		4	27	30.1 W.						
Long.,		9	46	08 E.						
H. A.,		14	13	38 W.						
		9	46	22 E.						
		{ 2^h	13^m	38^s						
		{33°	24′	30″						

t,	33	24	30	sec.	.07843		
d,	57	39	12	tan.	.19838	cosec.	.07323
h,	23	56	01			sin.	9.60818
180°−ϕ'',	117	51	52 S.	tan.	.27681	sin.	9.94648
ϕ',	64	52	49 N.			cos.	9.62789
Lat.,	52	59	03 S.				

BY THE POLE STAR.

333. This method, confined to northern latitudes, is available when the star Polaris and the horizon are distinctly visible, the time of the observation being noted at the moment the altitude is measured.

Reduce the observed altitude of Polaris to the true altitude.

Reduce the recorded time of observation to the local sidereal time.

With this sidereal time take out the correction from Table I (Nautical Almanac), and add it to or subtract it from the true altitude, according to its sign. The result is the approximate latitude of the place.

EXAMPLE: 1917, June 10, at 10^h 40^m 30^s P. M., mean solar time, in longitude 74° west of Greenwich, suppose the true altitude of Polaris to be 39° 46′; required the latitude of the place.

		h	m	s
Local astronomical mean time		10	40	30
Reduction from Table 9 (Bowditch), for 10^h 40^m 30^s	+		1	45
Greenwich sidereal time of mean noon, June 10, page 2 (Nautical Almanac).		5	13	4
Reduction from Table 9 (Bowditch), for longitude (=4^h 56^m west, or plus).	+		0	49
Sum (having regard to signs) is equal to local sidereal time		15	56	8
			°	′
True altitude			39	46
Correction from Table I (Nautical Almanac)	+		0	55
Approximate latitude	+		40	41

For greater accuracy use the form in the American Ephemeris and Nautical Almanac, and Tables I and Ia.

Observations of Polaris for latitude should be made when practicable near the times of upper or of lower culminations (hour angle 0^h or 12^h). However, at sea, if made near elongation (hour angle 6^h or 18^h), the hour angle, and hence the local time, should be known within one minute.

334. The latitude may be approximately found from an altitude of Polaris by computation from the formula:

$$L = h \pm p \cos t,$$

in which,

h = true altitude, deduced from the observed altitude;

p = polar distance $= 90° - d$, the apparent declination being taken from the Nautical Almanac for the time of observation.

t = star's hour angle.

Reduce the recorded time of observation to the local sidereal time.

Take out, from the Nautical Almanac, the apparent right ascension of Polaris for the time of observation.

Subtract the apparent right ascension from the local sidereal time, and the remainder will be the hour angle.

To the log cosine of the hour angle add the logarithm of the polar distance in minutes; the number corresponding to the resulting logarithm will be a correction in minutes to be subtracted from the star's true altitude to find the latitude when the hour angle is less than 6^h or more than 18^h, and to be added to the star's true altitude to find the latitude when the hour angle is more than 6^h and less than 18^h.

EXAMPLE: June 11, 1916, from an observed altitude of Polaris, the true altitude was found to be 29° 5′ 55″. The time noted by a Greenwich chronometer was $13^h\ 41^m\ 26^s$; chro. corr. $-2^m\ 22^s$; Long. $5^h\ 25^m\ 42^s$ W.

Chro. time,		13^h	41^m	26^s	
C. C.,	−		2	22	
G. M. T., 11^d,		13	39	04	
R. A. M. S.,	+	5	17	58.2	
Red. (Tab. 9),	+		2	14.5	
G. S. T.,		18	59	17	
R. A. ✱,	−	1	29	19	
H. A. from Gr.,		17	29	58	W.
Long.,		5	25	42	W.
H. A.,		12	04	16	W.
t,		11^h	55^m	44^s	E.
		178°	56′	00″	

h,		29°	05′	55″	
$p \cos t$,	+	1	08	36	
Lat.,		30	14	31	N.

R. A. ✱,			$1^h\ 29^m\ 19^s$
Dec.,			88° 51′ 24″ N.
p,			1° 08′ 36″ / 68′.6
p,	68′.6	log	1.83632
t,	178° 56′	cos (−)	9.99992
$p \cos t$, −	68′.6 / 1° 08′ 36″	log (−)	1.83624

If the computation is extended according to the following formula, inserting the value of p in seconds of arc:

$$L = h \pm p \cos t + \tfrac{1}{2} p^2 \sin 1'' \sin^2 t \tan h,$$

the resulting latitude is subject to no greater error than 1″; but if $p \cos t$ is the only correction applied to the altitude of Polaris, as in the above example, the resulting latitude, while subject to little error when Polaris is observed near the meridian, will have an error, when $t = 6$ hours, increasing with the altitude and amounting to 1′ when $h = 54°$ and to 3′ when $h = 68° 30'$.

DETERMINATION ON SHORE.

335. In finding the latitude on shore all the methods are available that have been heretofore explained for employment in finding the latitude at sea, provided only that an artificial horizon (art. 256) be supplied to take the place of the natural horizon of the sea in obtaining a measurement, by the sextant, of the altitude of the celestial body. In addition, other methods may be conveniently employed, involving the use of a theodolite or an altazimuth instrument, which the observer at sea is precluded from using because the employment of such instruments requires a steady platform.

If the observation is to be made with a theodolite or altazimuth, the instrument must first be placed level so that the line of collimation of the telescope revolves in the plane of the true meridian. This may be accomplished by means of laying off a true meridian from the true bearing of a terrestrial object from the instrument, as determined by the observation described in articles 360 and 361.

The altitude of the celestial body is then measured by bringing the horizontal cross wire of the telescope on the body at the instant the body transits the meridian or crosses the vertical cross wire of the telescope, and then reading the vertical circle.

The latitude is then deduced from the formula, $L=d+z$, after applying the proper corrections for index error, parallax, and refraction. The correction for index error is obtained by bringing the telescope to a horizontal position, as indicated by the level tube attached to the telescope, and taking the corresponding reading of the vertical circle immediately before and after each observation.

By observing the altitude of each of two stars with approximately the same zenith distance, one north of the zenith and one south of the zenith, a mean value for latitude resulting from the two observations may be obtained which is not affected by the error in estimating the absolute value of the astronomical refraction, but simply by the error in estimating a very small difference of refraction of two stars at nearly the same altitude.

This method of determining the latitude of a station is known as the Horrebow-Talcott method, and consists of the measurement of the small differences of zenith distance of two stars which transit at about the same time on opposite sides of the zenith. The effect of this procedure is the attainment of greater precision due to the increased accuracy of a differential measurement over the corresponding absolute measurement, the elimination of the use of a graduated circle in the measurement, and the fact that the computed result is not affected by the error in estimating the absolute value of the astronomical refraction, but simply by the error in estimating a very small difference of refraction of two stars at nearly the same altitude.

After measuring the difference of meridional zenith distances of two stars which transit at about the same time on opposite sides of the zenith and with nearly the same zenith distances, the latitude may be deduced from the following formula:

Let $d=$ declination of star south of zenith.
$d'=$ declination of star north of zenith.
$z=$ zenith distance of star south of zenith.
$z'=$ zenith distance of star north of zenith.

Then
$$L=d+z$$
$$L=d'-z'$$
$$2L=d+d'+z-z'$$
$$L=\tfrac{1}{2}(d+d')+\tfrac{1}{2}(z-z');$$

that is, the latitude is equal to one-half the sum of the declinations plus one-half the difference of zenith distances. The form of instrument used in measuring the differences of zenith distances is known as a zenith telescope, and consists of a telescope mounted on a horizontal axis supported by an upright or uprights in such a manner that it can be revolved about a vertical axis. A vertical circle is attached to the telescope for use in setting the telescope at the proper inclination with the horizontal to bring a particular star into the field of the telescope. A level tube is also attached to the telescope for use in bringing the telescope to the same inclination when observing on each of a pair of stars. The eyepiece of the telescope is fitted with a micrometer screw which operates a movable horizontal cross wire with which the bisections of the image of the observed body are made.

The process of observing for difference of zenith distances is as follows: If the first star of the pair of stars to be observed has a $\left\{\begin{matrix}\text{north}\\\text{south}\end{matrix}\right\}$ zenith distance the telescope is revolved about its vertical axis until it points $\left\{\begin{matrix}\text{north}\\\text{south}\end{matrix}\right\}$ in the plane of the meridian.

The approximate mean zenith distance of the two stars is then set off on the vertical circle, and the level bubble brought to the center of the tube. When the star appears in the field of the telescope the horizontal cross wire is brought to bisect the star and such bisection retained until the star crosses the vertical cross wire of the telescope. The micrometer head is then read. The telescope is then revolved through 180° about its vertical axis and brought to the same inclination with the horizontal by moving the telescope itself about its horizontal axis until the level bubble is at the center of the tube. In like manner the second star is bisected by the horizontal cross wire and the micrometer head again read. The difference between the two micrometer readings gives the difference of zenith distances of the two stars in terms of divisions of the micrometer, which when multiplied by the known angular value of one division of the micrometer gives the angular difference of the zenith distances of the two stars.

CHAPTER XIII.

LONGITUDE.

336. The *longitude* of a position on the earth's surface is measured by the arc of the equator intercepted between the *prime meridian* and the meridian passing through the place, or by the angle at the pole between those two meridians.

Meridians are great circles of the terrestrial sphere passing through the poles.

The *prime meridian* is that one assumed as the origin, passing through the location of some principal observatory, such as Greenwich, Paris, or Washington. That of Greenwich is the prime meridian not only for British and American navigators, but for those of many other nations.

Secondary meridians are those connected with the primary meridian, directly or indirectly, by exchange of telegraphic time signals.

Tertiary meridians are those connected with secondaries by carrying time in the most careful manner with all possible corrections.

Longitude is found by taking the difference between the hour angle of a celestial body from the prime meridian and its hour angle, at the same instant, from the local meridian. In determinations on shore the hour angle from the prime meridian may be found either from chronometers or from telegraphic signals; the local hour angle may be found by transit instrument or by sextant. In determinations at sea the chronometer and sextant give the only means available.

DETERMINATION ON SHORE.

337. Telegraphic Determination of Secondary Meridians.—In order to locate with accuracy the positions of prominent points on the coasts, it is necessary to refer them, by chronometric measurements, to secondary meridians of longitude which have been determined with the utmost degree of care.

Before the establishment of telegraphic cables, this was attempted principally through the observation of moon culminations, which seemed always to carry with them unavoidable errors, or by transporting to and fro a large number of chronometers between the principal observatory and the position to be located; and in this method it can be conceived that errors would be involved, no matter how thorough the theoretical compensation for error of the instruments.

By the aid of telegraph and radio, differences of longitude are determined with great accuracy, and an ever-increasing number of secondary meridian positions are thus established over the world; these afford the necessary bases in carrying on the surveys to map correctly the various coast lines, and render possible the publication of reliable and accurate navigators' charts.

338. To determine telegraphically the difference of longitude between two points, a small observatory containing a transit instrument, chronograph, break-circuit sidereal chronometer, and a set of telegraph instruments is established at each of the two points, and, being connected by a temporary wire with the cable or land line at each place, the two observatories are placed in telegraphic communication with each other.

By means of transit observations of stars, the error of the chronometer at each place on its own local sidereal time is well determined, and the chronometers are then accurately compared by signals sent first one way and then the other, the times of sending and receiving being very exactly noted at the respective stations. The error of each chronometer on local sidereal time being applied to its reading, the difference between the local times of the two places may be found, and consequently the difference of longitude. The time of transmission over the telegraph line is eliminated by sending signals both ways. By the employment of chronometers keeping sidereal time, the computation is simplified, though mean-time chronometers may be used.

339. Establishment of Tertiary Meridians.—Let it be supposed that the meridian distance between A and B is to be measured, of which A is a *secondary* meridian position accurately determined, and B a *tertiary* meridional position to be determined.

If possible, two sets of observations should be taken at A to ascertain the errors and rates of the chronometers. The run is then made to B, and observations made to determine local time, and hence the difference of longitude; and on the same spot altitudes of the sun, or of a number of pairs of stars, or both, should be taken to determine the latitude.

Now, if chronometer rates could be relied on to be uniform, this measurement would suffice, but since variations may always arise, the run back to A should be made, or to another secondary meridian position, C, and new rates there obtained. Finally, the errors of the chronometers on the day when the observations were made at the tertiary position should be corrected for the loss or gain in rate, and for the difference of the errors as thus determined.

When opportunity does not permit obtaining a *rate* at the secondary meridional station or stations, both before and after the observations at B, the navigator may obtain the *errors* only, and assume that the rate has been uniform between those errors.

A modification of the foregoing method which may sometimes prove convenient is to make the first and third sets of observations at the position of the tertiary meridian, and the intermediate one at the secondary meridian; in this case the error will be obtained at the secondary station and the rate at the tertiary.

Example: A vessel at a station A, of known longitude, obtained chronometer errors as follows:

May 27, noon, chro. slow, $7^m\ 18^s.9$.
June 3, noon, chro. slow, $7\ \ 12.7$;

then proceeding to a station B a series of observations for longitude was taken on June 17; after which, returning to A, the following errors were obtained:

July 3, noon, chro. slow, $7^m\ 00^s.7$,
July 10, noon, chro. slow, $6\ \ 59.8$.

Required the correct error on June 17.

May 27,	$-7^m\ 18^s.9$	July 3,	$-7^m\ 00^s.7$
June 3,	$-7\ \ 12.7$	July 10,	$-6\ \ 59.8$
Change,	$+\ \ 6.2$	Change,	$+\ \ 0.9$
Daily rate,	$+\ \ 0^s.89$	Daily rate,	$+\ \ 0^s.13$

Therefore, assuming that these rates were correct at the middle of the periods for which they were determined, we have,

May 30, Midnight, Rate,	$+0^s.89$
July 6, Midnight, Rate,	$+0.13$
Change of rate, 37 days,	-0.76
Daily change of rate,	$-0^s.021$

Change of rate for $3\frac{1}{2}$ days, $-0^s.07$; rate June 3, noon, $+0^s.89-0^s.07=+0^s.82$
Change of rate for $17\frac{1}{2}$ days, -0.37; rate June 17, noon, $+0.89-0.37=+0.52$

Mean daily rate, June 3 to 17,	$+0.67$
Total change of error, June 3 to 17,	$+0^m\ 09^s.38$
Error, June 3,	$-7\ \ 12.7$
Error, June 17,	$-7\ \ 03.3$

340. Single Altitudes.—The determination of longitudes on shore by single altitudes of a celestial body is identical in principle with the determination at sea by that method, which will be explained hereafter (art. 341). It may be remarked, however, that by taking observations on opposite sides of the meridian, at altitudes as nearly equal as posssible, a means is afforded, which is not available at sea, of eliminating certain constant errors of observation.

DETERMINATION AT SEA.

341. The Time Sight.—A method of determining longitude at sea is that of the *time sight,* sometimes called the *chronometer method.* The altitude of the body above the sea horizon is measured with a sextant and the chronometer time noted; the hour angle of the body is then found by the process described in article 316, Chapter XI.

If the sun is observed, the hour angle is equal to the local apparent time; the Greenwich apparent time may be determined by applying the equation of time to the Greenwich mean time as shown by the chronometer; the longitude is then equal to the difference between the local and the Greenwich apparent times, being east when the local time is the later and west when it is the earlier of the two.

If any other celestial body is employed, the hour angle from the local meridian, found from the sight, is compared with the hour angle from the Greenwich meridian to obtain the longitude; the Greenwich hour angle is found by converting the Greenwich mean time into Greenwich sidereal time in the usual manner, and then taking the difference between the latter and the right ascension of the body, the remainder being marked east or west, according as the Greenwich sidereal time is the lesser or greater of the two quantities; and as the local hour angle may be marked east or west according to the side of the meridian upon which it was observed, the name of the longitude will be indicated in combining the quantities.

342. As has been stated, the most favorable position of the celestial body for finding the hour angle from its altitude is when nearest the prime vertical, provided the altitude is not so small as to be seriously affected by refraction.

343. In determining the longitude at sea by this method, it is necessary to employ the latitude by account. This is seldom exactly correct, and a chance of error is therefore introduced in the resulting hour angle; the magnitude of such an error depends upon the position of the body relative to the observer. The employment of the Sumner line, which is to be explained in a later chapter, insures the navigator against being misled by this cause, and its importance is to be estimated accordingly.

Example: At sea, May 18, 1916, a. m.; Lat. 41° 33′ N.; Long. 33° 37′ W., by D. R., the following altitudes of the sun's lower limb were observed, and times noted by a watch compared with the Greenwich chronometer. Chro. corr., $+4^m\ 59^s.2$; I. C., $-30''$; height of the eye, 23 feet; C−W, $2^h\ 17^m\ 06^s$. Required the true longitude.

W. T.,		7^h	20^m	15^s
			20	47
			21	14
Mean,		7	20	45 .3
C−W,	+	2	17	06
Chro. t.,		9	37	51 .3
C. C.,	+		4	59 .2
G. M. T., 17^d,		21	42	50 .5
Eq. t.,	+		3	44 .1
G. A. T.,		21	46	34 .6

Obs. alt. ⊙,		29°	35′	30″
			41	20
			46	10
Mean,		29	41	00
Corr.,	+		9	04
h,		29	50	04
(Tab. 46),	+		9′	34″
I. C.,	−		0′	30″
Corr.,	+		9′	04″

Dec., $17^d\ 20^h$,		19° 30′.3 N.
H. D.,	+	0′.6
G. M. T.,		$1^h.7$
Corr.,	+	1′.02
Dec.,		19° 31′ 18″ N.
p,		70° 28′ 42″

Eq. t., $17^d\ 20^h$,		$3^m\ 44^s.3$
H. D.,	−	$0^s.1$
G. M. T.,		$1^h.7$
Corr.,	−	$0^s.17$
Eq. t.,		$3^m\ 44^s.1$
(*Add to mean time.*)		

h,	29°	50′	04″		
L,	41	33	00	sec.,	.12588
p,	70	28	42	cosec.,	.02571
	2)141	51	46		
s,	70	55	53	cos.,	9.51415
$s-h$,	41	05	49	sin.,	9.81779
					2)19.48353
G. A. T.,	21^h	46^m	$34^s.6$		
L. A. T.,	19	32	05 .5	sin. ½ t,	9.74176

Long., $\left\{\begin{matrix} 2^h\ 14^m\ 29^s.1 \\ 33^\circ\ 37'\ 16'' \end{matrix}\right\}$ W.

EXAMPLE: At sea, April 16, 1916, p. m., in Lat. 11° 47′ S., Long. 0° 20′ E., by D. R., observed an altitude of the star Aldebaran, west of the meridian, 23° 13′ 20″; chronometer time, $6^h 58^m 29^s$, chronometer fast of G. M. T., $2^m 27^s$; I. C., −2′ 00″; height of eye, 26 feet. What was the longitude?

Chro. t.,	6^h 58^m 29^s	Obs. alt. ✳,	23° 13′ 20″	R. A. ✳,	4^h 31^m $06^s.8$
C. C.,	− 2 27	Corr.,	− 9 15	Dec.,	16° 20′ 36″ N.
G. M. T.,	6 56 02	h,	23 04 05	p,	106° 20′ 36″
R. A. M. S.,	+1 37 11	(Tab. 46),	− 7′ 15″		
Red. (Tab. 9),	+ 1 09	I. C.,	− 2 00		
G. S. T.,	8 34 22	Corr..	− 9 15		
R. A. ✳,	4 31 07				
H. A. from Gr.,	4 03 15 W.				

h,	23° 04′ 05″		
L,	11 47 00	sec	.00925
p,	106 20 36	cosec	.01791
	2)141 11 41		
s,	70 35 50	cos	9.52141
$s-h$,	47 31 45	sin	9.86783
Gr. H. A.,	4^h 03^m 15^s W.		2)19.41640
H. A.,	4 05 42 W.	sin ½ t	9.70820
Long.,	{ 0^h 02^m 27^s / 0° 36′ 45″ } E.		

EXAMPLE: At sea, July 26, 1916, a. m., in Lat. 25° 12′ S., Long. 75° 30′ W., by D. R., observed an altitude of the planet Jupiter, east of the meridian, 32° 46′ 10″; watch time, $2^h 48^m 02^s$; C−W, $5^h 05^m 42^s$; C. C., $+2^m 18^s$; I. C., +1′ 30″; height of eye, 18 feet. Required the longitude.

W. T.,	2^h 48^m 02^s	Obs. alt. ✳	32° 46′ 10″	R. A., 25^d 0^h,	2^h 08^m 20^s	H. D.,	+ $0^s.9$
C−W,	5 05 42	Corr.,	− 4 09	Corr.	+ 18	G. M. T.,	$19^h.9$
Chro. t.,	7 53 44	h,	32 42 01	R. A.,	2 08 38	Corr.,	+ $17^s.9$
C. C.,	+ 2 18	(Tab. 46),	− 5′ 39″	Dec. 25^d 0^h,	11° 35′.9 N.	H. D.,	+ 0′.07
G. M. T., 25^d,	19 56 02	I. C.,	+ 1 30	Corr.,	+ 1.4	G. M. T.,	$19^h.9$
R. A. M. S., 0^h,	+ 8 11 26.8	Corr.,	− 4 09	Dec.,	11° 37′ 18″ N.	Corr.,	+ 1′.39
Red. (Tab. 9),	+ 3 16.5			p,	101° 37′ 18″		
G. S. T.,	4 10 45.3						
R. A. ✳,	2 08 38						
H. A. from Gr.,	2 02 07.3 W.						

$h.$,	32° 42′ 01″		
L,	25 12 00	sec	.04343
p,	101 37 18	cosec	.00900
	2)159 31 19		
s,	79 45 40	cos	9.24983
$s-h$,	47 03 39	sin	9.86456
Gr. H. A.,	2^h 02^m 07^s W.		2)19.16682
H. A.,	3 00 15 E.	sin ½ t	9.58341
Long.,	{ 5^h 02^m 22^s / 75° 35′ 30″ } W.		

As explained in relation to the examples in article 319, the sum found by adding together the four logarithms in each of the foregoing examples is the logarithmic haversine of the hour angle; and, hence, the haversine table may be applied in such solutions; thus, in the last example, entering Table 45 with 9.16682, the required hour angle is at once found to be 3^h 00^m 15^s.

CHAPTER XIV.

AZIMUTH.

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344. The *azimuth* of a body has been defined (art. 223, Chap. VII) as the arc of the horizon intercepted between the meridian and the vertical circle passing through the body; and the *amplitude* (art. 224) as the arc measured between the position of the body when its true altitude is zero and the east or west point of the horizon. The amplitude is measured from the east point at rising and from the west point at setting, and, if added to or subtracted from 90°, will agree with the azimuth of the body when in the true horizon. The azimuth is usually measured from the north point of the horizon in north latitude, and from the south point in south latitude, through 180° to the east or west; thus, if a body bore N. by E., its azimuth would be named N. 11¼° E. in north, or S. 168¾° E. in south latitude.

The determination of the azimuth of a celestial body is an operation of frequent necessity. At sea, the comparison of the true bearing with a bearing by compass affords the only means of ascertaining the error of the compass due to variation and deviation; on shore, the azimuth is required in order to furnish a knowledge of the variation, and is further essential in all surveying operations, the true direction of the base line being thus obtained.

345. There are various methods of obtaining the true azimuth of a celestial body, which will be described as follows: (*a*) *Amplitudes*, (*b*) *Time Azimuths*, (*c*) *Altitude Azimuths*, (*d*) *Time and Altitude Azimuths*. A further method, by means of the Summer line, will be explained later (Chap. XV). Still another operation pertains to this subject, namely: (*e*) The determination of the *True Bearing of a Terrestrial Object*.

AMPLITUDES.

346. The method of obtaining the compass error by amplitudes consists in observing the compass bearing of the sun or other celestial body when its center is in the true horizon, the true bearing, under such conditions, being obtained by a short calculation. Since the true horizon is not marked by any visible line (differing as it does from the visible horizon by reason of the effects of refraction, parallax, and dip), allowance may be made for the difference by an estimate of the eye, or else the observation may be made in the visible horizon and a correction applied.

347. When the center of the sun is at a distance above the horizon equal to its own diameter it is almost exactly in the true horizon; at such a time, note its bearing by compass, and also note (as in all observations for determining compass error) the ship's head by compass, and the angle and direction of the ship's heel.

Or, note the bearing at the instant at which the center of the body is in the visible horizon; in the case of the sun and moon, the correct bearing at that time may be most accurately ascertained by taking the mean of the bearings when the upper and the lower limbs of the disk are just appearing or disappearing.

348. *To find the true amplitude by computation*, there are given the latitude, L, and declination, d. The quantities are connected by the formula,

$$\sin \text{Amp.} = \sec \text{L} \sin d,$$

from a solution of which the amplitude is obtained.

To find the true amplitude by inspection enter Table 39 with the declination at the top and the latitude in the side column; under the former and opposite the latter will be given the true amplitude. **To obtain accurate results, interpolate for minutes of latitude and declination.**

To reduce the observed amplitude when taken in the visible horizon to what it would have been if taken in the true horizon, enter Table 40 with the latitude and declination to the nearest degree and apply the correction there found to the observed amplitude; the result will be the corrected amplitude by compass, which, by comparison with the true amplitude, gives the compass error. When the body observed is the sun, a star, or a planet, apply the correction, at rising in north latitude or at setting in south latitude, to the *right*, and at setting in north latitude or at rising in south latitude, to the *left*. For the moon, apply half the correction in a contrary direction.

EXAMPLE: At sea, in Lat. 11° 29′ N., the observed bearing of the sun, at the time of rising, when its center was estimated to be one diameter above the visible horizon, was E. 31° N.; corrected declination 22° 32′ N. Required the compass error.

By computation.

L	11° 29′	sec	.00878
d	22 32	sin	9.58345
True amp.	E. 23° 01′ N.	sin	9.59223
Obs. amp.	E. 31 00 N.		
Error,	7° 59′ E.		

By inspection (Table 39).

L, 11°.5 N. / *d*, 22 .5 N.	True amp.	E. 23°.0 N.
Obs. amp.		E. 31 .0 N.
Error,		8°.0 E.

EXAMPLE: At sea, in Lat. 25° 03′ S., the observed bearing of Venus, when in the visible horizon at rising, was E. 18° 30′ N., its declination being 21° 44′ N. Required the compass error.

By computation.

L	25° 03′	sec	.04290
d	21 44	sin	9.56854
True amp.	E. 24° 08′ N.	sin	9.61144
Comp. amp.	E. 18 48 N.		
Error,	5° 20′ W.		

By inspection (Table 39).

L,	25°.0 S.	True amp.	E. 24°.1 N.
d,	21 .7 N.		
Obs. amp.	E. 18°.5 N.	Comp. amp.	E. 18 .8 N.
Corr. (Tab. 40)	0.3 left.		
Error,			5°.3 W.

EXAMPLE: At sea, in Lat. 40° 27′ N., the mean of the observed bearings of the upper and lower limbs of the moon, when in contact with the visible horizon at setting, was W. 17° S.; declination, 21° 12′ S. What was the error of the compass?

By computation.

L	40° 27′	sec	.11863
d	21 12	sin	9.55826
True amp.	W. 28° 22′ S.	sin	9.67689
Comp. amp.	W. 16 42 S.		
Error,	11° 40′ W.		

By inspection (Table 39).

L,	40°.5 N.	True amp.	W. 28°.4 S.
d,	21 .2 S.		
Obs. amp.	W. 17°.0 S.	Comp. amp.	W. 16 .7 S.
Corr. (Tab. 40)	0.3 right.		
Error,			11°.7 W.

TIME AZIMUTHS.

349. In this method are given the hour angle, t, at time of observation, the polar distance, p, and the latitude, L; to find the azimuth, Z.

Any celestial body bright enough to be observed with the azimuth circle may be employed for observation; the conditions are, however, most favorable for solution when the altitude is low.

350. Take a bearing of the object, bisecting it if it has an appreciable disk, and note the time with a watch of known error. Record, as usual. the ship's head by compass and the amount of heel. If preferred, a series of bearings may be taken with their corresponding times, and the means taken.

351. First prepare the data as follows:

(*a*) Find the Greenwich time corresponding to the local time of observation.

(*b*) Take out the declination of the body from the Nautical Almanac; if the method of computation is employed, the polar distance and the co-latitude should be noted.

(*c*) Find the hour angle of the body by rules heretofore given.

44325°—18——10

This having been done, the true azimuth may be determined either by *Time Azimuth Tables*, by the graphic method of an *Azimuth Diagram*, or by *Solution of the Astronomical Triangle*. Owing to the possibility of more expeditious working, either of the first-named two is to be considered preferable to the last, and the navigator is recommended to supply himself with a copy of a book of Azimuth Tables, such as published by the Hydrographic Office, or with an Azimuth Diagram such as Weir's or Sigsbee's; an explanation of the method of use accompanies each of these.

352. To solve the triangle:

Let S = ½ sum of polar distance and co-Lat.
D = ½ difference of polar distance and co-Lat.
½t = ½ hour angle.
Z = true azimuth.

$$\text{Then,}\quad \tan X = \sin D \operatorname{cosec} S \cot \tfrac{1}{2} t;$$
$$\tan Y = \cos D \sec S \cot \tfrac{1}{2} t;$$
$$Z = X + Y, \text{ or } X \sim Y.$$

First Case.—If the half-sum of the polar distance and co-Lat. is *less* than 90°: take the sum of the angles X and Y, if the polar distance is *greater* than the co-Lat.; take the difference, if the polar distance is *less* than the co-Lat.

Second Case.—If the half-sum of the polar distance and co-Lat. is *greater* than 90°: always take the difference of X and Y, which subtract from 180°, and the result will be the true azimuth.

In either case, mark the true azimuth N. or S. according to the latitude, and E. or W. according to the hour angle. It may sometimes be convenient to use the supplement of the true azimuth, by subtracting it from 180° and reversing the prefix N. or S., in order to make it correspond to the compass azimuth when the latter is less than 90°.

The cotangent of half the hour angle may be found from Table 44 abreast the *whole* hour angle in the column headed "Hour P. M."

Example: At sea, in Lat. 30° 25′ N., Long. 5h 25m 42s W., the observed bearing of sun's center was N. 135° 30′ E., and the Greenwich mean time, December 3, 2h 36m 11s. The corrected declination of the sun was 22° 07′ S.; the equation of time (additive to mean time), 10m 03s. Required the error of the compass.

G. M. T. (Dec. 3),	2h 36m 11s
Long.,	− 5 25 42
L. M. T. (Dec. 2),	21 10 29
Eq. t.,	+ 10 03
L. A. T.,	21 20 32
t,	2h 39m 28s

co-Lat.,	59° 35′
p,	112 07
p+co-L,	171 42
S,	85 51
p−co-L,	52° 32′
D,	26 16

t	2h 39m 28s
S	85° 51′
D	26 16
X	50 44
Y	88 19
X+Y	139 03

cot ½ *t*	.44051
cosec	.00114
sin	9.64596
tan	.08761

cot ½ *t*	.44051
sec	1.14045
cos	9.95267
tan	1.53363

True azimuth,	N. 139° 03′ E.
Comp. azimuth,	N. 135 30 E.
Compass error,	3 33 E.

Example: At sea, in Lat. 2° 16′ N., the observed bearing of the sun's center was N. 85° 15′ E: sun's hour angle, 3h 44m 16s, and its declination, 7° 38′ N. Required the compass error.

co-Lat.,	87° 44′
p,	82 22
p+co-L,	170 06
S,	85 03
co-L−*p*,	5° 22′
D,	2 41

t	3h 44m 16s
S	85° 03′
D	2 41
X	5 03
Y	87 22
Y−X	82 19

cot ½ *t*	.27372
cosec	.00162
sin	8.67039
tan	8.94573

cot ½ *t*	.27372
sec	1.06406
cos	9.99952
tan	1.33730

True azimuth,	N. 82° 19′ E.
Comp. azimuth,	N. 85 15 E.
Compass error,	2 56 W

Example: At sea, in Lat. 16° 32′ S., observed bearing of Venus N. 56° 00′ W., its hour angle being $4^h\ 27^m\ 31^s$, and its declination 23° 12′ N. What was the error of the compass?

co-Lat.,	73° 28′	t	$4^h\ 27^m\ 31^s$	cot ½ t	.18022	cot ½ t	.18022
p,	113 12	S	93° 20′	cosec	.00074	sec	1.23549
		D	19 52	sin	9.53126	cos	9.97335
p+co-L,	186 40						
		X	27 16	tan	9.71222		
S,	93 20	Y	87 40			tan	1.38906
p−co-L,	39° 44′	Y−X	60 24				
D,	19 52	Z	119° 36′				

True azimuth,	S. 119° 36′ W.
Comp. azimuth,	S. 124 00 W.
Compass error,	4 24 W.

ALTITUDE AZIMUTHS.

353. This method is employed when the altitude of the body is observed at the same time as the azimuth; in such a case the hour angle need not be known, though the time of observation should be recorded with sufficient accuracy for the correction of the declination of the sun, moon, or a planet.

There are given the altitude, h, the polar distance, p, and the latitude, L; to find the azimuth, Z.

354. Take a bearing of the body by compass, bisecting it if the disk is of appreciable diameter, and simultaneously measure the altitude; note the time approximately. Observe also the ship's heading (by compass) and the heel.

Or a series of azimuths, with corresponding altitudes, may be observed, and the means employed.

355. Calculate the true altitude and declination from the observed altitude and the time. Then compute the true azimuth from the following formula:

$$\cos \tfrac{1}{2} Z = \sqrt{\cos s \cos (s-p) \sec L \sec h},$$

in which $s = \frac{1}{2}(h+L+p)$. The resulting azimuth is to be reckoned from the north in north latitude and from the south in south latitude.

It may occur that the term, $(s-p)$, will have a negative value, but since the cosine of a negative angle less than 90° is positive, the result will not be affected thereby.

Example: At sea, in Lat. 30° 25′ N., the observed bearing of the sun's center was N. 135° 30′ E., and its corrected altitude 24° 59′; the approximate G. M. T. was $2^h.6$, the declination at that time being 22° 07′ S. Required the compass error.

h	24° 59′	sec	.04267
L	30 25	sec	.06431
p	112 07		
	2) 167 31		
s	83 45	cos	9.03690
$s-p$	−28 22	cos	9.94445
			2) 19.08833*
½ Z	69 30	cos	9.54416
Z	139 00		

True azimuth,	N. 139° 00′ E.
Comp. azimuth,	N. 135 30 E.
Compass error,	3 30 E.

TIME AND ALTITUDE AZIMUTHS.

356. When, at the time of observing the compass bearing of a celestial body, the altitude is measured and the exact time noted, the true azimuth may be very expeditiously determined, a knowledge of the latitude being unnecessary.

In view of the simplicity of the computation, this method strongly commends itself to observers not provided with azimuth tables or diagram.

357. The observation is identical with that of the altitude azimuth (art. 354), with the exception that the times of observation must be *exactly* instead of *approximately* noted.

* Since the sum of the four logarithms in the example under article 355 is the logarithm of $\cos^2 \frac{1}{2} Z$, and since $\cos^2 \frac{1}{2} Z = \sin^2 (90° - \frac{1}{2} Z) =$ hav. (180°−Z), the haversine table may be applied in the solution of such examples; thus, entering Table 45 with 9.08833, the supplement of Z is at once found to have the value 40° 59′ 03″, and hence the required azimuth is 139° 00′ 57″.

358. Ascertain the declination of the body at time of sight, and correct the observed altitude; compute the hour angle. We then have:

$$\sin Z = \sin t \cos d \sec h,$$

from which the azimuth may be found.

This method has a defect in that there is nothing to indicate whether the resulting azimuth is measured from the north or the south point of the horizon; but as the approximate azimuth is always known, cases are rare when the solution will be in question.

EXAMPLE: At sea, in Lat. 30° 25′ N., Long. $5^h\ 25^m\ 42^s$ W., the observed bearing of the sun's center was N. 135° 30′ E.; its altitude at the time was 24° 59′; hour angle, $2^h\ 39^m\ 28^s$ (39° 52′), and declination, 22° 07′ S. Find the compass error. (See example under Altitude Azimuths and first example under Time Azimuths.)

t	39° 52′	sin 9.80686	True azimuth,	N. 139° 04′ E.
d	22 07	cos 9.96681	Comp. azimuth,	N. 135 30 E.
h	24 59	sec .04267		
			Compass error,	3 34 E.
Z	S. 40° 56′ E.	sin 9.81634		

TRUE BEARING OF A TERRESTRIAL OBJECT.

359. Thus far, sea observations for combined variation and deviation have been discussed, but if it becomes necessary, as in surveying, to ascertain the *True Bearing of a Terrestrial Object*, or to find the variation at a shore station, more accurate methods than the foregoing must be resorted to.

The most reliable method is that by an *Astronomical Bearing*. This consists in finding the true bearing of some well-defined object by taking the angle between it and the sun or other celestial body with a sextant or a theodolite, and simultaneously noting the time by chronometer, or measuring the altitude, or observing both time and altitude. It should always be noted whether the object is right or left of the sun.

360. *By Sextant.*—Measure the angular distance between the object and the sun's limb; and if there is a second observer, measure the altitude of the sun at the same moment and note the time. In the absence of an assistant, first measure the altitude of the sun; next, the angular distance between the sun and the object; then, a second altitude of the sun, noting the time of each observation. Also measure the altitude of the defined point above the sea or shore horizon.

By Theodolite.—This instrument is far more convenient than the sextant, for, being leveled, the horizontal angle between the sun and the object is at once given, no matter what may be the altitudes of the objects. In case the altitude of the sun is needed, it may be read accurately enough from the vertical circle, although not as finely graduated as the limb of the sextant. The error in altitude must, however, be found by the level attached to the telescope, since it will usually be found to differ from the levels of the horizontal circle. If, in directing the telescope to the sun, there is no colored eyepiece, an image of the sun may be cast on a piece of white paper held at a little distance from the eyepiece, and by adjusting the focus the shadow of the cross wires will be seen.

It should be understood that any celestial body may be used as well as the sun, and there are, in fact, certain advantages in the use of the stars; the sun is chosen for illustration, because it will usually be found most convenient to employ that body.

361. Find the true azimuth of the celestial body by one of the methods previously explained in this chapter, and apply to it the azimuth difference, or horizontal angle between the celestial and the terrestrial body, having regard to the direction of one from the other.

To find the azimuth difference from sextant observations, change the observed altitudes of the bodies into *apparent* altitudes by correcting them for index error of the sextant, dip, and semidiameter; change the observed angular distance into *apparent* angular distance, by correcting for index error and semidiameter. Then if $S = \frac{1}{2}$ (App. Dist. + App. Alt.☉ + App. Alt. Object), we have:

$$\cos \tfrac{1}{2} \text{ Az. Diff.} = \sqrt{\sec \text{App. Alt.}\odot \sec \text{App. Alt. Object} \cos S \cos (S - \text{App. Dist.})},$$

whence the azimuth difference is deduced.

When the theodolite is used, the horizontal angle is given directly. If only one limb of the sun is observed, it will be necessary to apply a correction for semidiameter (S. D.×sec h), but it is usual to eliminate this correction by taking the mean of observations of both limbs.

Example: From a. m. observations, in Lat. 30° 25′ 24″ N., Long. 81° 25′ 24″ W., obtained the following data for finding the true bearing of a station:

Watch time,	11ʰ 22ᵐ 36ˢ	Obs. Ang. Dist. ☉,	117° 07′ Left.
C−W,	5 21 18	Obs. 2 Ω,	71° 37′ 20″
Chro. corr.,	+ 2 16	Obs. alt. Station,	20′
		I. C.,	zero.
Dec. S.,	22° 56′ 27″		
Eq. t.,	+ 7ᵐ 00ˢ		
S. D.,	16′ 17″		

Required the true bearing of the object.

W. T.,	11ʰ 22ᵐ 36ˢ	2Ω,	71° 37′ 20″	*t*	8° 08′ 00″	sin	9.15069
C−W,	5 21 18			*d*	22 56 27	cos	9.96422
		Ω,	35 48 40	*h*	36 03 37	sec	.09239
Chro. t.,	4 43 54	S. D.,	+ 16 17				
C. C.,	+ 2 16			Z { S.	9° 17′ E.	sin	9.20730
		App. Alt.,	36 04 57	Z { N.	170 43 E.		
G. M. T.,	4 46 10	*p. & r.*,	− 1 13				
Eq. t.,	+ 7 00						
		h,	36 03 44				
G. A. T.,	4 53 10						
Long.,	− 5 25 42						
L. A. T.,	23 27 28						
t,	{0ʰ 32ᵐ 32ˢ / 8° 08′ 00″}						

Obs. Ang. Dist.,	117° 07′ 00″	App. Dist.	117° 23′			True bearing ☉,	170° 43′ E.
☉'s S. D.,	+ 16 17	App Alt. ☉	36 05	sec 0.09250		Az. Diff.,	125 00 Left.
		App. Alt. Object	20	sec 0.00001			
App. Ang. Dist.,	117 23 17					True bearing object, N.	45° 43′ E.
			2)153 48				
		S	76 54	cos 9.35536			
		S−App. Dist.	−40 29	cos 9.88115			
				2)19.32902			
		½ Az. Diff.	62° 30′	cos 9.66451			
		Az. Diff.	125 00				

Example: Same date and place and same objects as in the preceding example; measurement made with a theodolite, angular distance ☉, 123° 17′; object left of sun. Watch time, 11ʰ 16ᵐ 34ˢ.5; watch slow of L. A. T., 4ᵐ 53ˢ.5. Dec. ☉, 22° 56′ S. Required the true bearing. (See article 352.)

W. T.,	11ʰ 16ᵐ 34ˢ.5	co-Lat.,	59° 35′	*t*	0ʰ 38ᵐ 32ˢ	cot ½ *t*	1.07435	cot ½ *t*	1.07435
W. slow, +	4 53 .5	*p*,	112 56	S	86° 15′	cosec	.00093	sec	1.18440
				D	26 41	sin	9.65230	cos	9.95110
L. A. T.,	23 21 28 .0	*p*+co-L,	172 31						
				X	79° 24′	tan	.72758		
t,	0 38 32	S,	86 15	Y	89 39			tan	2.20985
		p−co-L,	53 21	X+Y	169 03				
		D,	26 41						

True bearing ☉,	N. 169° 03′ E.
Az. Diff.,	123 17 Left.
True bearing object, N.	45 46 E.

CHAPTER XV.

THE SUMNER LINE.

DESCRIPTION OF THE LINE.

362. The method of navigation involving the use of the Sumner line takes its name from Capt. Thomas H. Sumner, an American shipmaster, who discovered it and published it to the world. As a proof of its value, the incident which led to its discovery may be related:

"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 bank. The weather was now more boisterous, and very thick, and the wind still southerly; arriving about midnight, 17th December, within 40 miles, by dead reckoning, of Tuskar light, the wind hauled SE. 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 ENE. under short sail with heavy gales. At about 10 a. m. an altitude of the sun was observed, and the chronometer time noted; but, having run so far without observation, it was plain the latitude by dead reckoning was liable to error and could not be entirely relied upon.

The longitude by chronometer was determined, using this uncertain latitude, and it was found to be 15′ E. of the position by dead reckoning; a second latitude was then assumed 10′ north of that by dead reckoning, and toward the danger, giving a position 27 miles ENE. of the former position; a third latitude was assumed 10′ farther north, and still toward the danger, giving a third position ENE. of the second 27 miles. Upon plotting these three positions on the chart, they were seen to be in a straight line, and this line passed through Smalls light.

"It then at once appeared that the observed altitude must have happened at all the three points and at Smalls light and at the ship at the same instant."

Then followed the conclusion that, although the absolute position of the ship was uncertain, she must be somewhere on that line. The ship was kept on the course ENE., and in less than an hour Smalls light was made, bearing ENE. ½ E. and close aboard.

The latitude by dead reckoning was found to be 8′ in error, and if the position given by that latitude had been assumed correct, the error would have been 8 miles too far S., and 31′ 30″ of longitude too far W., and the result to the ship might have been disastrous had this wrong position been adopted. This represents one of the practical applications of the Sumner line.

The properties of the line thus found will now be explained.

363. Circles of Equal Altitude.—In figure 54, if EE′E″ represent the earth projected upon the horizon of a point A, and if it be assumed that, at some particular instant of time, a celestial body is in the zenith of that point, then the true altitude of the body as observed at A will be 90°. In such a case the great circle EE′E″, which forms the horizon of A, will divide the earth into two hemispheres, and from any point on the surface of one of these hemispheres the body will be visible, while over the whole of the other hemisphere it will be invisible. The great circle EE′E″, from the fact of its marking the limit of illumination of the body, is termed the *circle of illumination,* and from any point on its circumference the true altitude of the center of the body will be zero. If, now, we consider any small circle of the sphere, BB′B″, CC′C″, DD′D″, whose plane is parallel to the plane of the circle of illumination and which lies within the hemisphere throughout which the body is visible, it will be apparent that the true altitude of the body at any point of the circumference of one of these circles is equal to its true altitude at any other point of the same circumference; thus the altitude of the body at B is equal to its altitude at B′ or B″, and its altitude at D is the same as at D′ or D″.

It therefore follows that at any instant of time there is a series of positions on the earth at which a celestial body appears at the same given altitude, and these positions lie in the circumference of a circle described upon the earth's surface whose center is at that position which has the body in the zenith, and whose radius depends upon the zenith distance, or—what is the same thing—upon the altitude. Such circles are termed *circles of equal altitude*. It is important to note that an observer making an instantaneous transit through the latitudes and longitudes passed over by any rhumb line or loxodromic curve drawn within the hemisphere of illumination, through the point A, will experience no astronomical difference, with reference to the observed body in the zenith of A, save an altitude difference.

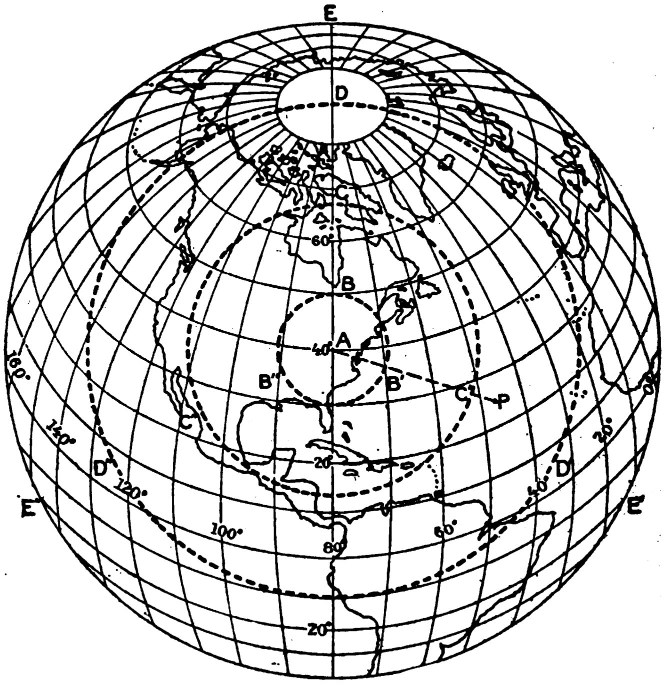

FIG. 54.

364. The data for an astronomical sight comprise merely the time, declination, and altitude. The first two fix the position of the body and may be regarded as giving the latitude and longitude of that point on the earth in whose zenith the body is found; the zenith distance (the complement of the altitude) indicates the distance of the observer from that point; but there is nothing to show at which of the numerous positions fulfilling the required conditions the observation may have been taken. A number of navigators may measure the same altitude of a body at the same instant of time, at places thousands of miles apart; and each proceeds to work out his position with identical data, so far as this sight is concerned. It is therefore clear that a single observation is not enough, in itself, to locate the point occupied by the observer, and it becomes necessary, in order to fix the position, to employ a second circle, which may be either that of another celestial body or that of the same body given by an observation when it is in the zenith of some other point than when first taken; knowing that the point of observation lies upon each of two circles, it is only possible that it can be at one of their two points of intersection; and since the position of the ship is always known within fairly close limits, it is easy to choose the proper one of the two. Figure 55 shows the plotting of observations of two bodies vertically over the points A and A′ upon the earth, the zenith distances corresponding respectively to the radii AO and A′O.

365. THE SUMNER LINE.—In practice, under the conditions existing at sea, it is never necessary to determine the whole of a circle of equal altitude, as a very small portion of it will suffice for the purposes of navigation; the position is always known within a distance which will seldom exceed 30 miles under the most unfavorable conditions, and which is usually very much less; in the narrow limits thus required, the arc of the circle will practically coincide with the tangent at its middle point, and may be regarded as a straight line. Such a line, comprising so much of the circle of equal altitude as covers the probable limits of position of the observer, is called a *Sumner line* or *Line of position.*

The latter designation has also a more extended meaning, embracing any line, straight or curved, which forms a locus of the ship's position, whether it be obtained from observations of celestial bodies or from bearings or distances of terrestrial objects.

366. Since the direction of a circle at any point—that is, the direction of the tangent—must be perpendicular to the radius at that point, it follows that the Sumner line always lies in a direction at right angles to that in which the body bears from the observer. Thus, in figure 55, it may be seen that $m\ m'$ and $n\ n'$, the extended Sumner lines corresponding to the bodies at A and A′, are respectively perpendicular to the bearings of the bodies OA and OA′. This fact has a most important application in the employment of the Sumner line.

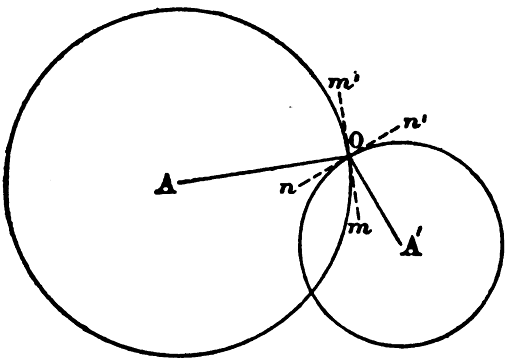

FIG. 55.

367. USES OF THE SUMNER LINE.—The Sumner line is valuable because it gives to the navigator a knowledge of all of the probable positions of his vessel, while a sight worked with a single assumed latitude or longitude gives but one of the probable positions; it must be recognized that, in the nature of things, an error in the assumed coordinate will almost invariably exist, and its possible effect should be taken into consideration; the line of position reveals the difference of longitude due to an error in the latitude, or the reverse.

Since the Sumner line is at right angles to the bearing, it may be seen that when the body bears east or west—that is, when it is on the prime vertical—the resulting line runs north and south, coinciding with a meridian; if, in this case, two latitudes are assumed, the deduced longitudes will be the same. When the body bears north or south, or is on the meridian, the line runs east and west, and practically coincides with a parallel of latitude; in such a case, two assumed longitudes will give the same latitude. Any intermediate bearing gives a Sumner line inclined to both meridians and parallels; if the line agrees in direction more nearly with the meridian, latitude should generally be assumed and the longitude worked; if it is nearer a parallel, the reverse course is usually preferable. The values of the assumed coordinates may vary from 10′ to 1°, according to circumstances.

368. The greatest benefit to be derived from the Sumner method is when two lines are worked and their intersection found. The two lines may be given by different bodies, which is generally preferable, or two different lines may be obtained from the same body from observations taken at different times. The position given by the intersection of two lines is more accurate the more nearly the lines are at right angles to each other, as an error in one line thus produces less effect upon the result. When two observations of the same body are taken, the position of the ship at the time of first sight must be brought forward to that at the second in considering the intersection; if, for example, a certain line is determined, and the ship then runs NW. 27 miles, it is evident that her new position is on a line parallel with the first and 27 miles to the NW. of it; a second line being obtained, the intersection of this with the first line, as corrected for the run, gives the ship's position.

Besides the employment of two lines for intersection with each other, a single line may be made to serve various useful purposes for the navigator. These are described in article 389, Chapter XVI.

METHODS OF DETERMINATION.

369. There are three methods in common use for determining the Sumner line:

(*a*) THE CHORD METHOD: To assume two values of one coordinate and find the corresponding values of the other. Two values of the latitude may be assumed and the longitudes determined, as was done by Capt. Sumner on the occasion that led to the discovery of his method; or else two values of the longitude may be assumed and the latitudes determined. Two points are fixed in this way, and the line joining them is the Sumner line.

(*b*) THE TANGENT METHOD: To assume either one latitude or one longitude and determine the corresponding coordinate. This gives one point of the Sumner line. The azimuth of the observed celestial body is then ascertained, and a line is drawn through the determined point at right angles to the direction in which the body bore at the time of the sight. This will be the Sumner line.

(*c*) In accordance with the method of Saint Hilaire, to be described in article 371, to lay off from an assumed geographical position, along the line of direction in which the body bore at the time of the sight, the determined distance to the Sumner line.

370. It follows that if the Sumner line be located by the first method and its direction thus defined, the azimuth of the observed body may be determined by finding the angle made by the line with the meridian and adding or subtracting 90°.

EXAMPLE: At sea, July 26, 1916, a. m., in Lat. 25° 12′ S., Long. 75° 30′ W., by D. R., observed an altitude of the planet Jupiter, east of the meridian, 32° 46′ 10″; watch time, $2^h 48^m 02^s$; C − W, $5^h 05^m 42^s$; C. C., + $2^m 18^s$; I. C., + 1′ 30″; height of eye, 18 feet. Required the Sumner line.

From a solution of this same problem for a single longitude (art. 343, Chap. XIII), the following were found: H. A. from Gr., $2^h 02^m 07^s$ W.; *h*, 32° 42′ 01″; *p*, 101° 37′ 18″. Assume values of Lat. 25° 02′ and 25° 22′ S.

h	32° 42′ 01″							
L_1	25 02 00	sec	.04284		L_2	25° 22′ 00″	sec	.04403
p	101 37 18	cosec	.00900				cosec	.00900
	2)159 21 19							
s_1	79 40 40	cos	9.25330		s_2	79 50 40	cos	9.24630
s_1-h	46 58 39	sin	9.86397		s_2-h	47 08 39	sin	9.86514
Gr. H. A.	$2^h 02^m 07^s$ W.		2)19.16911*		Gr. H. A.	$2^h 02^m 07^s$		2)19.16447
H. A.$_1$	3 00 45 E.	$\sin \frac{1}{2} t_1$	9.58455		H. A.$_2$	2 59 44	$\sin \frac{1}{2} t_2$	9.58224
Long.$_1$	$5^h 02^m 52^s$ / 75° 43′ 00″ W.				Long.$_2$	$5^h 01^m 51^s$ / 75° 27′ 45″ W.		

A comparison of these results with those obtained by the solution with a single latitude shows that the hour angle, and consequently the longitude, corresponding to the latitude 25° 12′ S. are the means of those corresponding to the latitudes here used; and therefore that the assumption that the Sumner line is a straight line is accurate.

The line of the same sight might also have been found as follows:

Working with the single latitude 25° 12′ S., it was found that the corresponding longitude was 75° 35′ 30″ W. Now, by referring to an azimuth table or azimuth diagram, the azimuth corresponding to Lat. 25°.2 S., Dec., 11°.6 N., H. A., $3^h 00^m.2$ E. is S. 124° 30′ E.; therefore the Sumner line extends S. 34° 30′ E.

The line may therefore be defined in either of two ways, thus:

A_1 {25° 02′ 00″ S. / 75 43 00 W.} A_2 {25° 22′ 00″ S. / 75 27 45 W.}

Or, A {25° 12′ 00″ S. / 75 35 30 W.} Line runs S. 34° 30′ E.

By inspection of the coordinates of A_1 and A_2 it may be seen that—

+20′ diff. lat. makes −15′.25 diff. long.; or
+20 miles diff. lat. makes −13.8 miles departure.

Therefore by reference to Table 2 it appears that the line runs about S. 34° 30′ E., and the azimuth of the body is S. 124° 30′ E.; thus the results obtained by the two methods agree.

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* As explained in article 319 the addition of the four logarithms gives the logarithmic haversine of the hour angle, and, hence, the haversine table may be applied in such solutions; thus, entering Table 45 with 9.16911, the corresponding hour angle is at once found to be $3^h 00^m 45^s$, and entering with 9.16447, the hour angle is found to be $2^h 59^m 44^s$.

EXAMPLE: At sea, May 18, 1916, a. m., Lat. 41° 33′ N., Long. 33° 37′ W., by D. R., the mean of a series of observed altitudes of the sun's lower limb was 29° 41′ 00″; the mean watch time, $7^h\ 20^m\ 45^s.3$; C. C., $+4^m\ 59^s.2$; I. C., −30″; height of the eye, 23 feet; C−W, $2^h\ 17^m\ 06^s$. Required the Sumner line.

From a solution of this same problem for a single longitude (art. 343, Chap. XIII) the following were found: G. A. T., $21^h\ 46^m\ 35^s$; h, 29° 50′ 04″; p, 70° 28′ 42″. Assume values of the latitude 41° 03′ and 42° 03′ N.

h	29° 50′ 04″						
L_1	41 03 00	sec	.12255	L_2	42° 03′ 00″	sec	.12927
p	70 28 42	cosec	.02571			cosec	.02571
	2)141 21 46						
s_1	70 40 53	cos	9.51959	s_2	71 10 53	cos	9.50863
s_1-h	40 50 49	sin	9.81560	s_2-h	41 20 49	sin	9.81995
G. A. T.,	$21^h\ 46^m\ 35^s$		2)19.48345	G. A. T.	$21^h\ 46^m\ 35^s$		2)19.48356
L. A. T.,₁	19 32 07	sin ½ t_1	9.74172	L. A. T.,₂	19 32 05	sin ½ t_2	9.74178
Long.,₁	$2^h\ 14^m\ 28^s$ / 33° 37′ 00″ W.			Long.,₂	$2^h\ 14^m\ 30^s$ / 33° 37′ 30″ W.		

A_1 {41° 03′ 00″ N. / 33 37 00 W. A_2 {42° 03′ 00″ N. / 33 37 30 W. +60′ diff. lat. makes +0′.5 long. +60 miles diff. lat. makes +0.4 mile departure.

Line runs, N. ¼° W. Azimuth, N. 89¾° E.

The same sight worked with a single latitude, 41° 33′ N., as was done in the original example, with azimuth taken from tables or diagram, gives:

A {41° 33′ 00″ N. / 33° 37′ 16″ W. Azimuth, N. 89° 37′ E. Line runs, N. 0° 23′ W.

This example illustrates the case in which an observation is taken practically on the prime vertical; the azimuth shows the bearing to be within 0° 23′ of true East, and the Sumner line is therefore within 0° 23′ of the meridian; a variation of 30′ in either direction from the dead reckoning latitude makes a difference of only 15″ in the longitude.

EXAMPLE: October 10, 1916, in Lat. 6° 20′ S. by account, Long. 30° 21′ 30″ W.; chro. time, $12^h\ 45^m\ 10^s$; observed altitude of moon's upper limb, 70° 15′ 30″, bearing north and east; I. C., −3′ 00″; height of eye, 26 feet; chro. fast of G. M. T., $1^m\ 37^s.5$. Required the Sumner line.

From a solution of the same problem with a single longitude (art. 332, Chap. XII), the following values are obtained: H. A. from Greenwich, $1^h\ 16^m\ 51^s$ W.; h, 70° 11′ 03″; d, 10° 03′ 00″ N. Assume the longitudes 30° 10′ and 30° 30′ W.

Gr. H. A.	$1^h\ 16^m\ 51^s$ W.	Gr. H. A.	$1^h\ 16^m\ 51^s$
Long.,₁	2 00 40 W.	Long.,₂	2 02 00
t_1	$0^h\ 43^m\ 49^s$ / 10° 57′ 15″	t_2	$0^h\ 45^m\ 09^s$ / 11° 17′ 15″

t_1	10° 57′ 15″	sec .00799			
d	10 03 00	tan 9.24853	cosec	.75819	
h	70 11 03		sin	9.97349	A_1 {6° 29′ 33″ S. / 30 10 00 W.
ϕ''_1	10 13 57 N.	tan 9.25652	sin	9.24955	
ϕ'_1	16 43 30 S.		cos	9.98123	
Lat.,₁	6 29 33 S.				
t_2	11° 17′ 15″	sec .00848			
d	10 03 00	tan 9.24853	cosec	.75819	
h	70 11 03		sin	9.97349	A_2 {6° 16′ 22″ S. / 30 30 00 W.
ϕ''_2	10 14 38 N.	tan 9.25701	sin	9.25002	
ϕ'_2	16 31 00 S.		cos	9.98170	
Lat.,₂	6 16 22 S.				

Working by the other method, and finding the azimuth, we have:

$$A\begin{cases}6^\circ\ 21'\ 39''\ S.\\30\ \ 21\ \ 30\ \ W.\end{cases}\qquad \text{Line runs N. } 55^\circ\ 50'\ W.$$

It might be shown that the results check with each other, as in previous cases.

Example: At sea, July 12, 1916, in Lat. 50° N., Long., 40° W., observed circum-meridian altitude of the sun's lower limb, the time by a chronometer regulated to Greenwich mean time being $2^h\ 41^m\ 39^s$; chro. corr., $-2^m\ 30^s$; I. C., $-3'\ 0''$; height of the eye, 15 feet. Find the Sumner line.

From the solution of the same problem for a single latitude (art. 330, Chap. XII) the following values were obtained: G. A. T., $2^h\ 33^m\ 45^s$; h, 61° 57′ 01″; d, 21° 58′ 38″ N.; a (Tab. 26), 2″.5. Assume longitudes 39° 45′ and 40° 15′ W.

Gr. H. A.	2^h	33^m	45^s		Gr. H. A.		2^h	33^m	45^s	
Long._1	− 2	39	00		Long._2		− 2	41	00	
t_1		5	15		t_2			7	15	
h	61°	57′	01″		h		61°	57′	01″	
at_1^2	+	1	09		at_2^2		+	2	11	
H_1	61	58	10		H_2		61	59	12	
z_1	28	01	50	N.	z_2		28	00	48	N.
d	21	58	38	N.	d		21	58	38	N.
L_1	50	00	28	N.	L_2		49	59	26	N.

The line given by these coordinates is then:

$$A_1\begin{cases}50^\circ\ 00'\ 28''\ N.\\39\ \ 45\ \ 00\ \ W.\end{cases}\qquad A_2\begin{cases}49^\circ\ 59'\ 26''\ N.\\40\ \ 15\ \ 00\ \ W.\end{cases}$$

This shows that the Sumner line lies so nearly in a due east-and-west direction that a difference of longitude of 30′ makes a difference of latitude of only 1′.

From the azimuth tables or diagram, it is found that the azimuth of the sun corresponding to Lat. 50° N. Dec. 22° N. and H. A. $6^m\ 15^s$ E., is N. 176° 55′ E. Therefore, using the values given by the earlier solution, the line is defined as follows:

$$A\begin{cases}49^\circ\ 59'\ 59''\ N.\\40\ \ 00\ \ 00\ \ W.\end{cases}\qquad \text{Line runs N. } 86^\circ\ 55'\ E.$$

The direction of the line thus given and of the one found from the double coordinates may be shown to agree as in examples before given.

THE METHOD OF SAINT HILAIRE OR OF THE CALCULATED ALTITUDE.

371. The foregoing parts of this work have set forth that, when the purpose of the navigator is to find the latitude, the observed celestial body should be situated on or near the meridian or at least not remote from it, and that he must apply different rules according as the body is on or near or more remote from the meridian; and again when his purpose is to find the longitude, the observed celestial body should be situated on or near or at least not remote from the prime vertical, and that he must then apply another set of rules. It is also explained in article 363 that a navigator, who has measured the altitude of a celestial body at a known instant of time, has really located his geographical position on the circumference of a circle whose radius is equal to the zenith distance (90° − Alt.) and whose center is the geographical position of the celestial body or that point on the earth's surface which falls vertically under the observed body at the instant of observation.

It has been pointed out that practical needs are concerned only with that portion of the circumference of the circle of position which lies in the vicinity of the estimated position of the ship, and, having seen how this portion may be determined and laid down by methods depending upon the computation of latitudes and longitudes, we proceed to extend our view to the accomplishment of this purpose by a method which is now rapidly growing in favor among practical navigators, because it brings the whole of astronomical navigation under a single rule by rendering the course of procedure the same, whatever the situation in the heavens of the observed body may be, provided only that the conditions admit of accurate measurement of its altitude.

In figure 54, the circumference of a circle of position is represented as having been laid down from A, the geographical position of the observed body, as a center, with a radius AC′ equal to the zenith distance of the observed celestial body; but it is evident that a small arc of the circumference, not differing sensibly from a straight line within the extent of a Sumner line, may be determined in the following manner from a neighboring geographical position, as at P, inside or outside of the circumference and at or near the position of the ship as given by dead reckoning:

1. Find the great-circle distance (zenith distance) and bearing (azimuth) of the geographical position of the observed body A from the observer's assumed position P.

2. Take the difference, in minutes of arc (nautical miles), between this zenith distance AP due to the observer's assumed position, and the zenith distance AC′ found from the true altitude resulting from observation.

3. Lay off this difference, which is called the altitude-difference, or intercept, from the assumed position P either away from or toward the observed celestial body according as the true altitude by observation is less or greater than the altitude at the assumed position, and through the point thus reached draw a line at right angles to the bearing.

The line so drawn will evidently be a tangent to the circumference of the circle of position, and will be so nearly coincident with this circumference throughout such length as the Sumner line need have, in all those cases in which the zenith distance is as great as 10°, that the tangent itself may be taken as the true line of position. Obviously the only trigonometrical computation that occurs under this method is in calculating the length and bearing of the great-circle arc joining the position P, which is assumed or known from the dead reckoning, with the geographical position A, which is always in a latitude equal to the declination of the observed celestial body at the instant of observation and in a longitude equal to the hour angle of the body from the prime meridian (Greenwich). In the case of the sun the Greenwich hour angle is expressed by Greenwich apparent time, and in the case of any other celestial body the Greenwich hour angle is found as explained in article 293, using G. M. T. instead of L. M. T.

372. Being strictly in the nature of calculating the great-circle distance and course between two points whose latitudes and longitudes are given, these computations may be made according to articles 190 and 191, Chapter V; but in practice it is unnecessary to do so, since various altitude and azimuth tables [a] give the distance and azimuth or true bearing, on the globe or on the celestial sphere, of any place from every other place, and consequently the altitude and azimuth, or zenith distance and bearing, that any celestial body would have at any given time to an observer situated in any given geographical position. So that an observer in a geographical position as yet unknown, about to measure the altitude of a celestial body for the purpose of deducing geographical position, may assume beforehand a geographical position in the region of his station and find from the tables the altitude and azimuth which the celestial body would have if observed from the assumed position; and then, comparing the altitude so taken from the tables with the true altitude obtained by measurement, may at once find the Sumner line by laying off from the assumed geographical position along the direction of the bearing an intercept, called the altitude-difference, and drawing through its extremity a line at right angles to the bearing.

After finding the altitude-difference or intercept, the simplest procedure consists in laying it off on the chart from the assumed position and drawing the Sumner line through its extremity, but if, for any reason, this process is not desirable, the latitude and longitude of the extremity of the intercept, which is a point on the Sumner line, called the "computed point," may be found by the use of the Traverse Tables, or may be computed directly.

The exact position of the observer on the Sumner line is, of course, indeterminate from one observation, unless either the latitude or longitude of the observer's position be known beforehand, but the computed point will always be nearer to the actual position of the observer than the dead reckoning or assumed position is. To obtain a fix, that is, to find the actual position, it is necessary to determine the intersection of the first Sumner line with another line of position, which may be another Sumner line or a line of bearing or any other line containing the ship's position at the same time.

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[a] Hydrographic Office Publication No. 200—Altitude, Azimuth, and Line of Position.
Hydrographic Office Publication No. 201—Simultaneous Altitudes and Azimuths of Celestial Bodies.

When the specially prepared altitude and azimuth tables are not preferred, the required azimuth or true bearing of the observed celestial body may be taken from the time azimuth tables, and the zenith distance, and hence the altitude, that the observed body would have at the instant of observation to an observer in the assumed geographical position may be conveniently computed by the following formula:

$$\text{hav } z = \text{hav } (L \sim d) + \cos L \cos d \text{ hav } t$$

or by the formula of haversines, which is rid of all doubt as to the algebraical signs of the quantities and requires reference to only one trigonometrical table:

$$\text{hav } z = \text{hav (Co. L} - \text{P. D.)} + \{\text{hav (Co. L} + \text{P. D.)} - \text{hav (Co. L} - \text{P. D.)}\}\text{hav } t$$

These are modifications of the fundamental formula:

$$\sin h = \sin L \sin d + \cos L \cos d \cos t,$$

which is itself often preferred for the computation of the altitude from the latitude, declination, and hour angle.

In the computations which follow, the parts of the several formulæ have been designated as follows:

IN THE COSINE-HAVERSINE FORMULA:

$$\text{hav } \theta = \cos L \cos d \text{ hav } t;$$

hence,

$$\text{hav } z = \text{hav } (L \sim d) + \text{hav } \theta$$

IN THE HAVERSINE FORMULA:

$$\text{hav A} = \text{hav (Co. L} + \text{P. D.)} - \text{hav (Co. L} - \text{P. D.)}$$
$$\text{hav B} = \{\text{hav (Co. L} + \text{P. D.)} - \text{hav (Co. L} - \text{P. D.)}\} \text{ hav } t;$$

hence,

$$\text{hav } z = \text{hav (Co. L} - \text{P. D.)} + \text{hav B}.$$

IN THE SINE-COSINE FORMULA:

$$A = \sin L \sin d, \quad B = \cos L \cos d \cos t;$$

hence,

$$\sin h = A + B.$$

Example: At sea, May 18, 1916, a. m., Lat. 41° 33′ N.; Long. 33° 37′ W., by D. R., the mean of a series of observed altitudes of the sun's lower limb was 29° 41′ 00″; the mean watch time, $7^h\ 20^m\ 45.3^s$; C. C., $+4^m\ 59.2^s$; I. C., −30″; height of eye, 23 feet; C.−W., $2^h\ 17^m\ 06^s$. Required the Sumner line.

From a solution of the same problem under article 343, Chapter XIII, and article 370, Chapter XV, the following are taken from among the prepared data: G. A. T., $21^h\ 46^m\ 35^s$; P. D., 70° 28′ 42″; h, 29° 50′ 04″, and, therefore, the measured zenith distance (90°−h), 60° 09′ 56″.

Assume a position in latitude 41° 30′ N. and longitude 33° 38′ 45″ or $2^h\ 14^m\ 35^s$ W., then the solution will be as follows:

L.	41° 30′ 00″	G. A. T.	$21^h\ 46^m\ 35^s$
		Long.	2 14 35 W.
Co. L.	48 30 00		
P. D.	70 28 42	L. A. T.	19 32 00 = t.

Note.—After obtaining the G. A. T., it will be seen that the longitude of the assumed position may be so chosen as to avoid seconds in the L. A. T. or H. A.

The azimuth found from the azimuth tables is N. 89° 37′ E.

BY THE COSINE-HAVERSINE FORMULA:

	t	$19^h\ 32^m\ 00^s$	log hav	9.48378
	L	41° 30′ 00″ N.	log cos	9.87446
	d	19° 31′ 18″ N.	log cos	9.97429
			log hav θ	9.33253[a]
			nat hav θ	0.21505
	L∼d	21° 58′ 42″..........	nat hav	0.03634
Calculated	z	60° 11′ 00″..........	nat hav	0.25139
		90° 00′ 00″		
Calculated	h	29 49 00		
Observed	h	29 50 04		
Altitude-difference		1′ 04″		

[a] The arrangement of Table 45 is such as to obviate the necessity of taking out the value of the angle in finding the natural haversine from the log. haversine, or vice versa.

BY THE HAVERSINE FORMULA:

Co. L+P. D.	118° 58′ 42″ nat hav	0. 74225
Co. L−P. D.	21 58 42 nat hav	0. 03634
nat hav A		0. 70591[a]
log hav A		9. 84876
log hav t		9. 48378
log hav B		9. 33254
nat hav B		0. 21505
nat hav (Co. L—P. D.)		0. 03634
nat hav z		0. 25139
Calculated z		60° 11′ 00″
		90 00 00
Calculated h		29 49 00
Observed h		29 50 04
Altitude-difference		1 04

BY THE SINE-COSINE FORMULA:

t	$19^h\ 32^m\ 00^s$				
	293° 00′ 00″			log cos	9. 59188
L	41 30 00 N.	log sin	9. 82126	log cos	9. 87446
d	19 31 18 N.	log sin	9. 52396	log cos	9. 97429
		log A	9. 34522	log B	9. 44063
		A	0. 22142		
				B	0. 27581
				A	0. 22142
Calculated h=29° 49′ 00″		nat sin=A+B			0. 49723

Since the observed altitude is higher than the calculated altitude, the observer's position is nearer to the observed body than the assumed position. Consequently the altitude-difference should be laid off in a direction to the east and north, 89° 37′, 1.0 nautical mile from the assumed position.

Or, by the Traverse Tables:

Course.	Distance.	Diff. Lat.	Dep.	Diff. Long.
89°. 6	1. 0	0′. 0 N.	1′. 0 E.	1′. 3 E.

Assumed position, Lat.	41° 30′ 00″ N.	Long.	33° 38′ 45″ W.
Diff. Lat.	00 N.	Diff. Long.	1 18 E.
Computed point on Sumner line,	41° 30′ 00″ N.		33° 37′ 27″ W.

The direction of the Sumner line, being at right angles to the azimuth or true bearing of the observed celestial body, runs N. 0° 23′ W. and S. 0° 23′ E. or 359° 37′ and 179° 37′.

EXAMPLE: At sea, October 10, 1916, in Lat. 6° 20′ S. by account, Long. 30° 21′ 30″ W.; chro. time, $12^h\ 45^m\ 10^s$; observed altitude of moon's upper limb, 70° 15′ 30″, bearing north and east; I. C., −3′ 00″; height of eye, 26 feet; chro. fast of G. M. T., $1^m\ 37^s.5$. Required the Sumner line.

From a solution of the same problem under article 332, Chapter XII, and again under article 370, Chapter XV, the following quantities are taken from among the prepared data: H. A. from Greenwich, $1^h\ 16^m\ 51^s$ W.; corrected altitude, h, 70° 11′ 03″; d, 10° 03′ 00″ N. and, hence, P. D., 100° 03′ 00″.

Assume a position in Lat. 6° 00′ S. and Long. 30° 27′ 45″ W.; then the solution will be as follows:

L	6° 00′ 00″ S.	Gr. H. A.	$1^h\ 16^m\ 51^s$ W.
		Long.	2 01 51 W.
Co. L	84 00 00		
P. D.	100 03 00	t	0 45 00

[a] The arrangement of Table 45 is such as to obviate the necessity of taking out the value of the angle in finding the natural haversine from the log. haversine, or vice versa.

BY THE COSINE-HAVERSINE FORMULA:

t	0h 45m 00s	log hav	7.98260
L	6° 00′ 00″ S.	log cos	9.99761
d	10 03 00 N.	log cos	9.99328
		log hav θ	7.97349
		nat hav θ	0.00941
L∾d	16° 03′ 00″	nat hav	0.01949
z	19 34 30	nat hav	0.02890
	90 00 00		
Calculated h	70 25 30		
Observed h	70 11 03		
Altitude-difference	14 27		

BY THE HAVERSINE FORMULA:

Co. L+P. D.	184° 03′ 00″	nat hav	0.99875
Co. L−P. D.	16 03 00	nat hav	0.01949
nat hav A			0.97926
log hav A			9.99090
log hav t			7.98260
log hav B			7.97350
nat hav B			0.00941
nat hav (Co. L−P. D.)			0.01949
nat hav z			0.02890
Calculated z			19° 34′ 30″
			90 00 00
Calculated h			70 25 30
Observed h			70 11 03
Altitude-difference			14 27

BY THE SINE-COSINE FORMULA:

t	0h 45m 00s				
	11° 15′ 00″			log cos	9.99157
L	6 00 00 S.	log sin	9.01923−	log cos	9.99761
d	10 03 00 N.	log sin	9.24181	log cos	9.99328
		log A	8.26104−	log B	9.98246
		A	=−0.01824	B	= 0.96044
				A	=−0.01824
		Calculated h=70° 25′ 30″		nat. sin=A+B	0.94220

The azimuth from the Azimuth Tables S. 145° 00′ E. or N. 35° 00′ E.

Since the observed altitude is lower than the calculated altitude, the observer's position is further removed from the observed body than the assumed position. Consequently the altitude-difference should be laid off to the south and west, 215° 14.5 nautical miles from the assumed position.

Or, by the Traverse Tables:

Course.	Distance.	Diff. Lat.	Dep.	Diff. Long.
215°	14.5	11′.9 S.	8′.3 W.	8′.4 W.

Assumed position, Lat.	6° 00′ 00″ S.	Long.	30° 27′ 45″ W.
Diff. Lat.	11 54 S.	Diff. Long.	8 24 W.
Computed point on Sumner line,	6 11 54 S.		30 36 09 W.

The direction of the Sumner line, being at right angles to the azimuth or true bearing of the observed body, is N. 55° 00′ W. and S. 55° 00′ E., or 305° 00′ and 125° 00′.

EXAMPLE: At sea, July 12, 1916, in Lat. 50° N., Long. 40° W., observed an ex-meridian altitude of the sun's lower limb, 61° 48′ 30″, the time by chronometer regulated to Greenwich mean time being $2^h\ 41^m\ 39^s$; chro. corr., $-2^m\ 30^s$; I. C., −3′ 00″; height of eye, 15 feet. Find the Sumner line.

From a solution of the same problem under article 330, Chapter XII, and again under article 370, Chapter XV, the following quantities are taken from among the prepared data: G. A. T., $2^h\ 33^m\ 45^s$; *h*, 61° 57′ 01″; *d*, 21° 58′ 38″ N.

Assume a position in Lat. 49° 50′ N., Long. 40° 11′ 15″ or $2^h\ 40^m\ 45^s$ W., then the solution will be as follows:

L.	49° 50′ 00″ N.	G. A. T.	$2^h\ 33^m\ 45^s$	*d*	21° 58′ 38″ N.
		Long.	2 40 45 W.		
Co. L	40 10 00			P. D.	68 01 22
P. D.	68 01 22	L. A. T.=*t*	0 07 00 E.		

BY COSINE-HAVERSINE FORMULA:

t	$0^h\ 7^m\ 00^s$	log hav	6. 36774
L	49° 50′ 00″ N.	log cos	9. 80957
d	21° 58′ 38″ N.	log cos	9. 96724
		log hav θ	6. 14455
		nat hav θ	0. 00014
L∼*d*	27° 51′ 22″	nat hav	0. 05793
z	27° 53′ 15″	nat hav	0. 05807
	90° 00′ 00″		
Calculated *h*	62 06 45		
Observed *h*	61 57 01		
Altitude-difference	9 44		

BY HAVERSINE FORMULA:

Co. L+P. D.	108° 11′ 22″	nat hav	0. 65607
Co. L−P. D.	27 51 22	nat hav	0. 05793
nat hav A			0. 59814
log hav A			9. 77681
log hav *t*			6. 36774
log hav B			6. 14455
nat hav B			0. 00014
nat hav (Co. L−P. D.)			0. 05793
nat hav *z*			0. 05807
Calculated *z*			27° 53′ 15″
			90 00 00
Calculated *h*			62 06 45
Observed *h*			61 57 01
Altitude-difference			9 44

BY THE SINE-COSINE FORMULA:

t	$0^h\ 07^m\ 00^s$				
	1° 45′ 00″........................			log cos	9. 99980
L	49 50 00 N.	log sin	9. 88319	log cos	9. 80957
d	21 58 38 N.	log sin	9. 57315	log cos	9. 96724
		log A	9. 45634	log B	9. 77661
		A	0. 28598	B	0. 59787
				A	0. 28598
Calculated *h*=62° 06′ 37″		nat sin	=	A+B	0. 88385

The azimuth from the Azimuth Tables: N. 176° 32′ E. or S. 3° 28′ E.

Since the observed altitude is lower than the calculated altitude, the observer's position is farther removed from the observed body than the assumed position. Consequently the altitude-difference should be laid off to the north and west, 356° 32′, 9.7 nautical miles from the assumed position.

Or, by the Traverse Tables:

Course.	Distance.	Diff. Lat.	Dep.	Diff. Long.
356°.5	9.7	9.7 N.	0′.6 W.	0′.9 W.

Assumed position, Lat.	49° 50′ 00″ N.	Long.	40° 11′ 15″ W.
Diff. Lat.	9 42 N.	Diff. Long.	0 54 W.
Computed point of Sumner line,	49 59 42 N.		40 12 09 W.

The direction of the Sumner line, being at right angles to the azimuth or true bearing of the observed body, is N. 86° 32′ E. and S. 86° 32′ W., or 86° 32′ and 266° 32′.

373. In the first of the three foregoing examples, the observed celestial body is represented as being near the prime vertical; in the second, remote from both the prime vertical and the meridian; and in the third, near the meridian. These examples have been solved in the preceding chapters by three different methods known, respectively, as the time sight, the ϕ' ϕ'', and the ex-meridian; but we have here treated all of them by one method, and have determined Sumner lines which are in agreement with those determined by the various preceding methods. And it would be likewise if we should take examples in which meridian altitudes have been observed. Inasmuch as the local hour angle of a celestial body is 0° at the time of its passage across the meridian of an observer, the second member of the right-hand side of the equation of haversines becomes zero in cases in which the meridian altitude has been observed, since the haversine of 0° is equal to zero. The equation therefore reduces to

$$\text{hav } z = \text{hav (Co. L} - \text{P. D.)}$$

or

$$z = (\text{Co. L} - \text{P. D.})$$

which leads at once to the usual formulae given in article 321, Chapter XII, for finding the latitude from a meridian altitude. By this we are taught the full interpretation of a meridian altitude, which is that it gives the latitude of the intersection with the local meridian of a Sumner line coinciding with a parallel of latitude.

374. In addition to the simplicity which arises from always working by the same rule, the navigator has, by this method, the further practical advantage of being able to do the most of the work of obtaining the Sumner line before taking the observation, since, in clear weather, he may, in selecting the assumed geographical position, assume an hour angle and calculate what time the chronometer or watch ought to show at the instant when the celestial body has this hour angle, and then observe the altitude at this instant; or, if anything should happen to make him a few seconds late in getting the altitude, he may alter the assumed longitude by a corresponding amount so as to make the hour angle right, and then the rest of the work will hold good.

After correcting the observed altitude and obtaining from it the true altitude, no more time need subsequently elapse in determining the Sumner line than is necessary to take the difference between the altitudes found by calculation and by observation and to rule a line at right angles to the bearing of the observed body through the point found by laying off this altitude-difference as an intercept from the assumed position.

375. It has already been remarked that the labor of performing such computations as the foregoing may be saved when a book of altitude and azimuth tables is at hand. These tables are arranged to be entered with the hour angle, the declination, and the latitude; and they contain the corresponding values of the altitude and azimuth. In the various books containing such tables, the special rules to be observed in their use are set forth.

44325°—18——11

It has been implied that when the altitude of the observed body is greater than 80° and, therefore, the zenith distance or radius of the circle of position is less than 10°, the tangent drawn to the circumference to represent the Sumner line could no longer be regarded as coinciding throughout its proper length with the arc of the circumference. When the zenith distance is 10°, the departure of the tangent from the circumference is one-tenth of a mile at a distance of 10 miles from the theoretical point of tangency and seven-tenths of a mile at a distance of 30 miles from the theoretical point of tangency. These departures are doubled when the zenith distance is reduced to 5°, and they are nearly ten times the amounts stated for 10° when the zenith distance is shortened to 1°.

There is not, however, any occasion for resorting to the proceeding of laying down a straight line as a substitute for an arc of the actual circle of position when the zenith distance is only a few degrees in length. In such cases the greatest convenience and the best results are found by drawing circles of position directly on the navigator's chart. For this purpose the polyconic chart, being issued to navigators throughout all latitudes from 20° to 60° north of the Equator in connection with the works of the United States Coast and Geodetic Survey, and therefore being available throughout a like extent of south latitude by mere inversion, is generally serviceable, because a chart embracing any certain parallels of latitude is available between these parallels of latitude throughout all longitudes; and the Mercator projection may also be used for this purpose within the Tropics, since the length of a minute of latitude as represented on this projection varies but little within tropical limits. For instance, it happens in crossing the tropical zone that, for a day or so, the sun is very near the zenith—perhaps not more than 1° away on one day and 2° or 3° on another. In such circumstances, having a chart of suitable scale embracing the parallels of latitude of the region in which the ship is situated, plot the sun's geographical position with Greenwich hour angle as longitude and declination as latitude, take on the dividers the zenith distance, or complement of the corrected altitude, and draw in a portion of the circumference of the actual circle of position lying near the position of the ship as given by dead reckoning. Then wait until the azimuth has changed 30° or so—which it does very rapidly near noon—and draw a second similar arc. The intersection of these arcs gives the ship's position with accuracy. Of course if the ship has moved in geographical place in the interval between the two sights, it will be necessary, in order to find the geographical position at the instant of the second sight, to move the first circle of position in direction and amount equal to the course and distance made good in the interval.

FINDING THE INTERSECTION OF SUMNER LINES.

376. The intersection of Sumner lines may be found either graphically or by computation.

(*a*) Graphic methods.—Each line may be plotted upon the chart of the locality in which the ship is being navigated, in accordance with the data for its determination (see art. 367), and the intersection thus found. This plan will commend itself especially when the vessel is near shore, as the chart in use will then probably be one of large enough scale, and it will be an advantage to see where the Sumner lines fall with reference to the soundings and landmarks. To aid the extension of this convenient practice on the ocean, where the navigator is usually furnished only with a general chart, position-line plotting sheets have been provided for the use of navigators upon an ample scale.

(*b*) Methods by Computation.—The finding of the intersection of two Sumner lines by computation may be divided into two cases:

Case I. When one line lies in a NE.-SW. direction, and the other in a NW.-SE. direction, as shown in figure 56.

Case II. When both lie in a NE.-SW., or both in a NW.-SE. direction, as shown in figure 57.

377. If each Sumner line is defined by the latitude and longitude of one of its points and the azimuth of the celestial body at right angles to whose true bearing the line runs, we may then, by means of Table 47, find the longitude of any other point on such a line when its difference of latitude from the known point has been ascertained. The numbers in Table 47 are values of the longitude factor, usually denoted by the letter F. They vary with the latitude of the observer and the celestial body's azimuth at right angles to the direction of the line, and express the change in longitude due to a change of 1′ in latitude along any given Sumner line. So that the difference of latitude between any two points of a line, being multiplied by the longitude factor, will give the difference of longitude between those points.

Turning to figures 56 and 57 and considering the Sumner lines $A_1 A_2$ and $B_1 B_2$ there represented to be defined by the azimuth at right angles to each and the latitudes and longitudes of the points A_1 and B_1, respectively, we proceed to show the relations which exist for determining the latitude and longitude of the fix at their intersection by means of the tabulated longitude factors. The line PO being drawn perpendicular to the parallel of latitude through the points A_1 and B_1, the latitude of the intersection will be a distance OP from the common latitude of A_1 and B_1, and its longitude will be a distance $A_1 O$ from A_1 and $B_1 O$ from B_1. Let F_1 and F_2 represent the longitude factors from Table 47 for the Sumner lines $A_1 A_2$ and $B_1 B_2$, respectively. Then, since F_1 is the difference of longitude corresponding to a change of 1′ of latitude along the line $A_1 A_2$, the difference of longitude $A_1 O$ must be equal to F_1 multiplied into the number of minutes of latitude in the length OP. Therefore,

$$A_1 O = OP \times F_1,$$

and likewise

$$B_1 O = OP \times F_2;$$

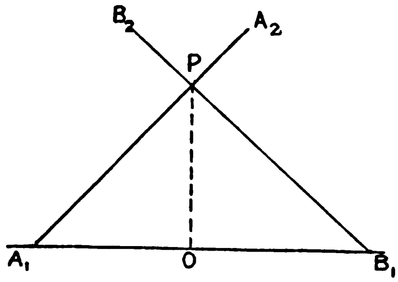

FIG. 56.

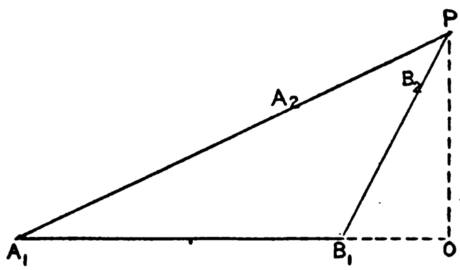

FIG. 57.

and, since the known difference of longitude between the points A_1 and B_1 is composed of the sum of $A_1 O$ and $B_1 O$ in Case I, and the difference of $A_1 O$ and $B_1 O$ in Case II, we have

$$A_1 O + B_1 O = A_1 B_1 = OP \times F_1 + OP \times F_2 = OP\ (F_1 + F_2), \text{ in Case I, and}$$
$$A_1 O - B_1 O = A_1 B_1 = OP \times F_1 - OP \times F_2 = OP\ (F_1 - F_2), \text{ in Case II.}$$

From which, placing the known quantities on the right-hand side of the equations, thus:

$$OP = \frac{A_1 B_1}{F_1 + F_2}, \text{ in Case I, and}$$

$$OP = \frac{A_1 B_1}{F_1 - F_2}, \text{ in Case II.}$$

Hence, we obtain the difference of latitude from the common parallel of A_1 and B_1 to the point of intersection by dividing the known difference of longitude between the points A_1 and B_1 by the sum of the longitude factors of the respective Sumner lines in Case I, and by their difference in Case II.

Having determined OP and hence the latitude of the point of intersection of the Sumner lines, we proceed to multiply OP by F_1 to get the difference of longitude A_1O, and apply that difference to the known longitude of A_1 to find the longitude of the point of intersection P; and also, as a check, to multiply OP by F_2 to get the difference of longitude B_1O, which, being applied to the longitude of B_1, gives again the longitude of the point of intersection, P.

The following is a summary of the successive steps to be taken in following this method:

1. Make a rough sketch of the Sumner lines whose intersection is to be fixed in latitude and longitude, classifying them under Case I or Case II.

2. Take from Table 47 the longitude factors F_1 and F_2, respectively, for the Sumner lines.

3. If the given coordinates of the points on the two lines have not a common latitude, reduce them to a common latitude by multiplying the difference between the latitudes of the points on the two lines by the longitude factor of one of the lines and applying the product to the longitude of the point on that line. The sketch will show whether the difference of longitude is to be added or subtracted, and the result will be the longitude of a point of this line on the common parallel of latitude.

4. The difference between the longitudes of the points of the two Sumner lines, on the common parallel, divided by the sum of the longitude factors (F_1+F_2), will give the difference of latitude between the point of intersection and the common parallel, when the lines are classified under Case I; and the difference between the longitudes of the points of the two Sumner lines, on the common parallel, divided by the difference of the longitude factors (F_1-F_2), will give the difference of latitude between the point of intersection and the common parallel, when the lines are classified under Case II.

The sketch will show whether the intersection of the Sumner lines lies to the northward or southward of the common parallel, and hence whether the difference of latitude is to be added to or subtracted from the latitude of the common parallel.

5. Having found the difference of latitude between the point of intersection of the Sumner lines and the common parallel, multiply this difference by the longitude factor of each line and apply the products each to the longitude of its corresponding line on the common parallel. The products are applied in opposite directions in Case I, and both of them must lead to the same longitude for the point of intersection; and the products are applied in the same direction in Case II, and in this case also both of them must lead to the same longitude for the point of intersection.

EXAMPLE: Find the intersection of the Sumner lines defined below by the latitude and longitude of a single point on each and by the respective azimuths of the celestial bodies upon which the lines depend.

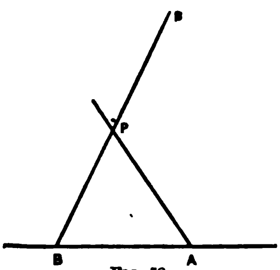

FIG. 58.

$$A\begin{cases}25^\circ\ 40'\ S.\\115^\circ\ 31'\ W.\end{cases}\text{Azimuth, at right angles to line, N. }51^\circ\text{ E.}$$

$$B\begin{cases}25^\circ\ 25'\ S.\\115^\circ\ 33'.5\ W.\end{cases}\text{Azimuth, at right angles to line, N. }72^\circ\text{ W.}$$

From Table 47:

Longitude factor for line A=0.90=F_1.
Longitude factor for line B=0.36=F_2.

Reduce the given points to a common parallel of latitude by transferring the point on line B to the latitude of the point on line A,

$$(25^\circ\ 40'\ S.-25^\circ\ 25'\ S.)\times F_2=15'\times 0.36=\quad 5'.4\ W.$$
$$115^\circ\ 33'.5\ W.$$
$$\overline{115^\circ\ 38'.9\ W.}$$

Hence we have for the point on the line B at which the latitude is the same as the latitude of the point on the line A,

$$B\begin{cases}25^\circ\ 40'\ S.\\115^\circ\ 38'.9\ W.\end{cases}\text{Azimuth, at right angles to line, N. }72^\circ\text{ W.}$$

We now have two Sumner lines, under Case I, whose common latitude is 25° 40′ S. and whose longitudes on the common parallel are:

115° 38′.9 W.
115° 31′.0 W.

7′.9=Diff. Long. on common parallel.

$$\frac{7.9}{F_1+F_2}=\frac{7.9}{.90+.36}=\frac{7.9}{1.26}=6.27\text{ Diff. Lat. between intersection and common parallel.}$$

Corrections in longitude:

$$6.27\times F_1=6.27\times 0.90=5'.64$$
$$6.27\times F_2=6.27\times 0.36=2.26$$

Long. A	115° 31′.00 W.	Long. B	115° 38′.90 W.	Lat. common parallel	25° 40′.00 S.
Diff. Long.	5 .64 W.	Diff. Long.	2 .26 E.	Diff. Lat.	6 .27 N.
Intersection	115 36 .64 W.		115 36 .64 W.		25 33 .73 S.

EXAMPLE: Find the intersection of the Sumner lines defined below:

A {49° 30′ N. / 5 24 .8 W.} Azimuth, at right angles to line, N. 81° W.
B {49° 30′ N. / 5 25 .8 W.} Azimuth, at right angles to line, N. 31° W.

A sketch of the lines shows their classification to be under Case II.

From Table 47:

Longitude factor for line A $=0.24=F_1$.
Longitude factor for line B $=2.57=F_2$.

Diff. Long. on common parallel=5° 25′ .8—5° 24′ .8=1′ .0.

$\frac{1.0}{F_2-F_1}=\frac{1.0}{2.57-0.24}=\frac{1.0}{2.33}=0.429$=Diff. Lat. between intersection and common parallel.

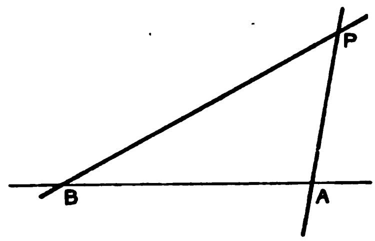

FIG. 59.

Corrections in longitude:

$$0.429\times F_1=0.429\times 0.24=0.10.$$
$$0.429\times F_2=0.429\times 2.57=1.10.$$

Long. A	5° 24′ .8 W.	Long. B	5° 25′ .8 W.	Lat. common parallel	49° 30′ .0 N.
Diff. Long.	0 .1 E.	Diff. Long.	1 .1 E.	Diff. Lat.	0 .4 N.
Intersection	5 24 .7 W.		5 24 .7 W.		49 30 .4 N.

378. If the two geographical positions defining two Sumner lines have a common longitude instead of a common latitude, as represented in figures 60 and 61, their intersection may be found by means of the latitude factors tabulated in Table 48, in a manner similar to the use of the longitude factors in connection with the Sumner lines whose known points have a common latitude. The latitude factors vary with the latitude of the observer and the celestial body's azimuth at right angles to the direction of the line, and express the change in latitude due to a change of 1′ in longitude along any given Sumner line. So that the difference of longitude between any two points of a line being multiplied by the latitude factor will give the difference of latitude between those points.

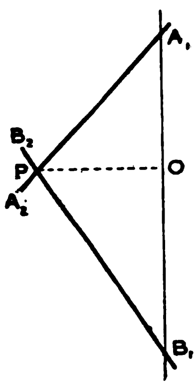

FIG. 60.

The latitude factors of two Sumner lines whose intersection is to be found are usually denoted by the letters f_1 and f_2, and the successive steps to be taken in finding the intersection are here summarized:

1. Make a rough sketch of the Sumner lines whose intersection is to be fixed in latitude and longitude, classifying them under Case I or Case II.
2. Take from Table 48 the latitude factors f_1 and f_2, respectively, for the Sumner lines.
3. The difference between the latitudes of the points of the two Sumner lines, in the common longitude, divided by the sum of the latitude factors (f_1+f_2), will give the difference of longitude between the point of intersection and the common meridian when the lines are classified under Case I; and the difference between the latitudes of the

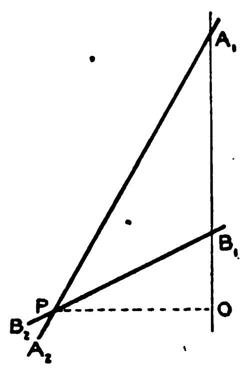

FIG. 61.

points of the two Sumner lines, in the common longitude, divided by the difference of the latitude factors $(f_1 - f_2)$, will give the difference of longitude between the point of intersection and the common meridian when the lines are classified under Case II.

The sketch will show whether the intersection of the Sumner lines lies to the eastward or westward of the common meridian, and hence whether the difference of longitude is to be added to or subtracted from the common longitude.

4. Having found the difference of longitude between the point of intersection of the Sumner lines and the common longitude, multiply this difference by the latitude factor of each line and apply the products each to the latitude of its corresponding line on the common meridian. The products are applied in opposite directions in Case I, and both of them must lead to the same latitude for the point of intersection; and the products are applied in the same direction in Case II, and in this case also both of them must lead to the same latitude for the point of intersection.

EXAMPLE: Find the intersection of the Sumner lines defined below:

A $\begin{cases} 40° \ 13'.55 \text{ N.} \\ 71 \ \ 14 \ .86 \text{ W.} \end{cases}$ Azimuth, at right angles to line, N. 57°. 6 W.

B $\begin{cases} 40° \ 06'.40 \text{ N.} \\ 71 \ \ 14 \ .86 \text{ W.} \end{cases}$ Azimuth, at right angles to line, N. 77° W.

A sketch of the lines shows their classification to be under Case II.

From Table 48:

Latitude factor for line A=1. 23=f_1.
Latitude factor for line B=3. 32=f_2.

Diff. Lat. on common meridian=7'.15.

$$\frac{7.15}{f_2-f_1}=\frac{7.15}{3.32-1.23}=\frac{7.15}{2.09}=3'.42$$ Diff. Long. between intersection and common meridian.

Corrections in latitude:

$3.42 \times f_1 = 3.42 \times 1.23 = \ 4'.20$
$3.42 \times f_2 = 3.42 \times 3.32 = 11.35$

Lat. A	40° 13'. 55 N.	Lat. B	40° 06'. 40 N.	Long. on common meridian	71° 14'. 86 W.
Diff. Lat.	4 . 20 N.	Diff. Lat.	11 . 35 N.	Diff. Long.	3. 42 E.
Intersection	40° 17'. 75 N.		40° 17'. 75 N.		71° 11'. 44 W.

379. When a Sumner line is defined by the latitudes and longitudes of two of its points, the longitude factor for the line may be found by dividing the difference between the longitudes of the two given points by the difference between their latitudes; and the latitude factor, being the reciprocal of the longitude factor, may be found by dividing the difference between the latitudes of the two given points by their difference of longitude.

The method of finding the intersection of Sumner lines by longitude and latitude factors, described in articles 377 and 378, may, therefore, be applied as well when the lines are defined by pairs of geographical positions as when they are defined by the azimuth and one geographical position.

380. The modification of the methods for finding the intersection of two Sumner lines, where there is a run between the observations from which they are deduced, will be readily apparent. It is known that at the time of taking a sight the vessel is at one of the points of the Sumner line, but which of the various points represents her precise position must remain in doubt until further data are acquired. Suppose, now, that after an observation, the vessel sails a given distance in a given direction; it is clear that while her exact position is still undetermined it must be at one of the series of points comprised in a line parallel to the Sumner line and at a distance and direction therefrom corresponding to the course and distance made good; hence, if a second sight is then taken, the position of the vessel may be found from the intersection of two lines—one, the Sumner line given by the second observation, and the other a line parallel to the first Sumner line but removed from it by the amount of the intervening run.

Positions may be brought forward graphically on a chart by taking the course from the compass rose with parallel rulers, and the distance by scale with dividers. If one of the methods by computation be adopted, the point or points of the first line are brought forward by the traverse tables, using middle latitude sailing. The direction of a Sumner line as determined from the azimuth of the body always remains the same, whatever shift may be made in the position of the point by which the line is further defined.

EXAMPLE: Taking the Sumner lines, which are defined in the first example under article 377, by the latitude and longitude of a point of each and by the respective azimuths of the celestial bodies upon which the lines depend, as follows:

A { 25° 40′ S. / 115 31 W. } Azimuth, at right angles to line, N. 51° E.

B { 25° 25′ S. / 115 33 .5 W. } Azimuth, at right angles to line, N. 72° W.

and supposing the vessel from which the observations were taken that gave these lines to have run N. 54° E. (true) 35 miles in the interval between the sights, find the position of the vessel at the time of the second sight.

The point A, in 25° 40′ S. and 115° 31′ W., is first transferred to the point A′, 35 miles N. 54° E.(true) from A, by the method of Middle Latitude Sailing (article 177) by means of the Traverse Tables, thus:

From Table 2, course N. 54° E.; Dist., 35 miles; we find Diff. Lat. 20.6 N., Dep. 28.3 E. Therefore,

Lat. A	25° 40′ S.	Lat. A	25° 40′ S.
Diff. Lat.	20 .6 N.	Lat. A′	25 19 .4 S.
Lat. A′	25 19 .4 S.		2)50 59 .4
		Middle Lat.	25 29 .7

From Table 2, Middle Lat. (course), 25½°, Dep. (Lat.), 28.3 E., we find Diff. Long. (Dist.), 31.3 E. Therefore,

Longitude A,	115° 31′ W.
Diff. Long.	31 .3 E.
Longitude A′,	114 59 .7 W.

The Sumner lines whose intersection is to be found are therefore defined as follows:

A′ { 25° 19′.4 S. / 114 59 .7 W. } Azimuth, at right angles to the line, N. 51° E.

B { 25° 25′ S. / 115 33 .5 W. } Azimuth, at right angles to the line, N. 72° W.

From Table 47:

Longitude factor for line A′=0.90=F_1
Longitude factor for line B =0.36=F_2

Reduce the given points to a common parallel of latitude by transferring the point on line B to the latitude of the point on line A′,

(25° 19′.4 S.−25° 25′ S.)×F_2=−5.6×0.36= 2′.0 E.
115° 33 .5 W.
115 31 .5 W.

Hence we have for the point on the line B at which the latitude is the same as the latitude of the point on the line A′,

B′ { 25° 19′.4 S. / 115 31 .5 W. }

We now have two Sumner lines, A′ and B′, under Case I, whose common latitude is 25° 19′.4 S., and whose longitudes on the common parallel are 114° 59′.7 and 115° 31′.5. Hence, the difference of longitude on the common parallel is

115° 31′.5 W.	
114° 59′.7 W.	
31 .8	= Diff. Long. on common parallel.

$$\frac{31.8}{F_1+F_2}=\frac{31.8}{0.90+0.36}=\frac{31.8}{1.26}=25.2 = \text{Diff. Lat. between intersection and common parallel.}$$

Corrections in longitude:

$$25.2\times F_1=25.2\times 0.90=22.7$$
$$25.2\times F_2=25.2\times 0.36=\ 9.1$$

Long. A′	114° 59′.7 W.	Long. B′	115° 31′.5 W.	Lat. common par.	25° 19′.4 S.
Diff. Long.	22 .7 W.	Diff. Long.	9.1 E.	Diff. Lat.	25 .2 N.
Intersection	115 22 .4 W.		115 22 .4		24 54 .2 S.

CHAPTER XVI.

THE PRACTICE OF NAVIGATION AT SEA.

381. Having set forth in previous chapters the methods of working dead reckoning and of solving problems to find the latitude, longitude, chronometer correction, and azimuth from astronomical observations, it will be the aim of the present chapter to describe the conditions which govern the choice and employment of the various problems, together with certain considerations by which the navigator may be guided in his practical work at sea.

382. Departure and Dead Reckoning.—On beginning a voyage, a good departure must be taken while landmarks are still in view and favorably located for the purpose; this becomes the origin of the dead reckoning, which, with frequent new departures from positions by observation, is kept up to the completion of the voyage, thus enabling the mariner to know, with a fair degree of accuracy, the position of his vessel at any instant.

At the moment of taking the departure, the reading of the patent log (which should have been put over at least long enough previously to be regularly running) must be recorded, and thereafter at the time of taking each sight and at every other time when a position is required for any purpose, the log reading must also be noted. It is likewise well to read the log each hour, for general information as to the speed of the vessel as well as to observe that it is in proper running order and that the rotator has not been fouled by seaweed or by refuse thrown overboard from the ship. It is a good plan to record the time by ship's clock on each occasion that the log is read, as a supplementary means of arriving at the distance will thus be available in case of doubt. If a vessel does not use the patent log but estimates her speed by the number of revolutions of the engines or the indications of the chip log, the noting of the time becomes essential. A good sight is of no value unless one knows the point in the ship's run at which it was taken, so that the position it gave may be brought forward with accuracy to any later time.

383. General Description of the Day's Work.—The routine of a day's work at sea consists in working the dead reckoning, an a. m. time sight and azimuth taken when the sun is in its most favorable position for the purpose, a meridian altitude of the sun (or, when clouds interfere at noon, a sight for latitude as near the meridian as possible), and a p. m. time sight and azimuth. This represents the minimum of work, and it may be amplified as circumstances render expedient; but no part of it should ever be omitted unless cloudy weather renders its performance impossible.

384. Morning Sights.—The morning time sight and azimuth should be observed, if possible, when the sun is on the prime vertical. As the body bears east at that time, the resulting Sumner line is due north and south, and the longitude will thus be obtained without an accurate knowledge of the latitude. Another reason for so choosing the time is that near this point of the sun's apparent path the body is changing most slowly in azimuth, and an error in noting the time will have the minimum effect in its computed bearing. The time when the sun will be on the prime vertical—that is, when its azimuth is 90°—may be found from the azimuth tables or the azimuth diagram. Speaking generally, during half the year the sun does not rise until after having crossed the prime vertical, and is therefore never visible on a bearing of east. In this case it is best to take the observation as soon as it has risen above the altitude of uncertain atmospheric effects—between 10° and 15°.

A series of several altitudes should be taken, partly because the mean is more accurate than a single sight, and partly because an error in the reading of the watch or sextant may easily occur when there is no repetition. If the sextant is set in advance of the altitude on even five or ten minute divisions of the arc, and the time marked at contacts, the method will be found to possess various advantages. As the sight is being taken the patent log should be read and ship's time recorded. It is well, too, to make a practice of noting the index correction of the sextant each time that the sextant is used. The bearing of the sun by compass should immediately afterward be observed, and the heading by compass noted, as also the time (by the same watch as was used for the sight).

Before working out the sight, the dead reckoning is brought up to the time of observation, and the latitude thus found used as the approximate latitude at sight. It is strongly recommended that *every sight be worked for a Sumner line*, either by assuming two latitudes, or by using one latitude and the azimuth, or yet more advantageously by the method of Saint Hilaire.

The compass error is next obtained. From the time sight the navigator learns that his watch is a certain amount fast or slow of L. A. T., and he need only apply this correction to the watch time of azimuth to obtain the L. A. T. at which it was observed; then he ascertains the sun's true bearing from the azimuth tables or azimuth diagram, compares it with the compass bearing, and obtains the compass error; he should subtract the variation by chart and note if the remainder, the deviation, agrees with that given in his deviation table; but in working the next dead reckoning, if the ship's course does not change, the total compass error thus found may be used without separating it into its component parts. It should be increased or decreased, however, as the ship proceeds, by the amount of any *change* of the variation that the chart may show.

385. If there is any fear of the weather being cloudy at noon, the navigator should take the precaution, when the sun has changed about 30° in azimuth, to observe a second altitude and to record the appropriate data for another sight, though this need not actually be worked unless the meridian observation is lost. If it is required it may be worked for either a time sight or ϕ' ϕ'' sight, or by the Saint Hilaire method, according to circumstances, and a second Sumner line thus obtained, whose intersection with earlier Sumner line, brought forward for the run in the interval between the sights, will give the ship's position.

386. Noon Sights.—Between 11 and 11.30 o'clock (allowing for gain or loss of time due to the day's run) the ship's clocks should be set for the L. A. T. of the prospective noon position. The noon longitude may be closely estimated from the morning sight and the probable run. The navigator should also set his own watch for that time, to the nearest minute, and note exactly the number of seconds that it is in error. He may now compute the constant (art. 325, Chap. XII) for the meridian altitude. The daily winding of the chronometer is a most important feature of the day's routine, and may well be performed at this hour. At a convenient time before noon, the observations for meridian altitude are commenced and continued until the watch shows L. A. noon, at which time the meridian altitude is measured and the latitude deduced.

If the weather is cloudy and there is doubt of the sun being visible on the meridian an altitude may be taken at any time within a few minutes of noon, the time noted, and the interval from L. A. noon found from the known error of the watch. It is then the work of less than a minute to take out the a from Table 26, the at^2 from Table 27, and apply the reduction to the observed altitude to obtain the meridian altitude. Indeed, the method is so simple that it may be practiced every day and several values of the meridian altitude thus obtained, instead of only one.

387. It now becomes necessary to find the longitude at noon. This may be done graphically by a chart or by computation. The former plan needs no explanation. There are a number of variations in the methods of computation, one of which will be given as a type.

By the ship's run, work back the noon latitude to the latitude at a. m. time sight. If the Sumner line was found from two assumed latitudes which differed $+m$ minutes, while the corresponding longitudes differed $\pm n$ minutes, then 1′ difference of latitude causes $\pm\frac{n}{m}$ minutes difference of longitude. If the true latitude at sight is $\pm x$ minutes from one of the assumed latitudes, then $\pm x \times \frac{n}{m}$ is the corresponding difference of longitude. If the Sumner line was found from one assumed latitude and an azimuth, Z, the longitude factor of the line may be found from Table 47; and this multiplied by the difference between the true and assumed latitude will give the correction to be applied to the computed longitude corresponding to the assumed latitude. Having thus the longitude at sight, the longitude at noon is worked forward for the run. If the sights show a considerable current it should be allowed for, both in working back the latitude and in bringing up the longitude for the run between the sight and noon.

EXAMPLE: Suppose that an a. m. time sight, taken when the sun's azimuth was S. 39° 48′ E., has given a longitude of 30° 31′ W. when solved with a dead-reckoning latitude of 50° 54′ N. Suppose that when the noon latitude is worked back to the time of the a. m. sight, by means of the vessel's run, the true latitude at that time was found to be 50° 58′ N. The longitude was thus computed with a latitude that was 4′ too much to the southward. Find the corresponding error in longitude, and the longitude at the time of sight.

From Table 47, the longitude factor of the Sumner line passing through the geographical position whose latitude is 50° 54′ N. and whose longitude is 30° 31′ W., at right angles to the bearing S. 39° 48′ E., is 1.91. The computed longitude is therefore wrong by 4×1.91=7′.6; and according to the rule laid down in connection with the Explanation of Table 47, the correction in longitude must, in this case, be applied to the eastward.

Hence we have—

Longitude computed with D. R. Lat., 50° 54′ N	30° 31′ W.
Correction in long. due to change of 4′ in latitude to the northward	7. 6 E.
True longitude at the time of sight	30° 23. 4 W.

388. CURRENT AND RUN.—The current may be found by comparing the noon positions as obtained by observation and by dead reckoning; and the day's run is calculated from the difference between the day's noon position by observation and that of the preceding day. To "current" is usually attributed all discrepancies between the dead reckoning and observations; but it is evident that this is not entirely due to motion of the waters, as it includes errors due to faulty steering, improper allowance for the compass error, and inaccurate estimate of the vessel's speed through the water.

The noon position by observation becomes the departure for the dead reckoning that follows.

389. AFTERNOON SIGHTS.—The p. m. time sight and azimuth is similar to the morning observation.

390. SUMNER LINES.—By performing the work that has just been described a good position is obtained at noon each day, which, in a slow-moving vessel with plenty of sea room, may be considered sufficient; but conditions are such at times as to render it almost imperatively necessary that a more frequent determination of the latitude and longitude be made. If the vessel is near the land or in the vicinity of off-lying dangers, if she is running a great circle course requiring frequent changes, if she is making deep-sea soundings, if she has just come through a period of foggy or cloudy weather, or if the indications are that she is about to enter upon such a period, or if she is running at high speed, it is obviously inexpedient to await the coming of the next noon for a fix. The responsibilities resting upon the navigator require that he shall earlier find his ship's position; and, generally speaking, the greater the speed made by the vessel the more absolute is this requirement.

The key to all such determinations will lie in the Sumner line, and a clear understanding of the properties of such a line will greatly facilitate the solutions. The mariner must keep in mind two facts: First, that a single observation of a heavenly body can never, by itself, give the *point* occupied by an observer on the earth's surface; and second, that whenever any celestial body is visible, together with enough of the horizon to permit the measuring of its altitude, an observer may thereby determine a *line* which passes through his own position on the earth's surface in a direction at right angles to the bearing of the body.

It may readily be seen that if two Sumner lines are determined the observer's position must be at their intersection, and that that intersection will be most clearly marked when the angle between the lines equals 90°; hence, if two heavenly bodies are in sight at the same time the position may be found from the intersection of their Sumner lines, the angle of intersection being equal to the horizontal angle between the bodies. If only one body is in sight, as is generally the case when the sun is shining, one line of position may be gotten from an altitude taken at one time, and a second line from another altitude taken when it has changed some 30° in azimuth—usually, a couple of hours later. Bringing forward the first line for the intervening run, the intersection may be found.

With the general principles of the Sumner line clearly before him, the navigator will find no difficulty in making the choice of available bodies. If about to take a star sight, and sky and horizon are equally good in all quarters, two bodies should be taken whose azimuths differ as nearly as possible by 90°. If one body can be taken on or near the meridian, its bearing being practically north or south, the resulting Sumner line will be east and west—that is, it may be said that whatever the longitude (within its known limits) the latitude will be the same; the other sight may then be worked as a time sight with this single latitude, and time will thus be saved. The same is true if Polaris is observed, and it is a very convenient practice to take an altitude of that star at dawn and obtain a latitude for working the a. m. time sight of the sun. A similar case arises when a body is observed on the prime vertical, its Sumner line then runs north and south and coincides with a meridian; if the other body is favorably located for a $\varphi' \varphi''$ sight, it may be worked with a single longitude and the latitude thus found directly.

If it is not possible to obtain two lines and thus exactly locate the ship, the indications of a single line may be of great value to the navigator. A Sumner line and a terrestrial bearing will give the ship's position by their intersection in the same manner as two lines of position or two bearings; or the position of the ship on a line may be shown with more or less accuracy by a sounding or a series of soundings. If the body be observed when it bears in a direction at right angles to the trend of a neighboring shore line, the resulting line will be parallel with the coast and thus show the mariner his distance from the land, which may be of great importance even if his exact position on the line remains in doubt. If the bearing be parallel to the coast line, then the Sumner line will point toward shore; the value of a line that leads to the point that the vessel is trying to pick up is amply demonstrated by the experience of Captain Sumner that led to the discovery of the method. (Art. 362, Chap. XV.)

For especially accurate work three Sumner lines may be taken, varying in azimuth about 120°; if they do not intersect in a point, the most probable position of the ship is at the center of the triangle that they form.

If two pairs of lines be determined, each pair based upon observation of two bodies bearing in nearly opposite directions and at about the same altitude, the mean position that results from the intersection of the four lines will be as nearly as possible free from those errors of the instrument, of refraction, and of the observer, which can not otherwise be eliminated. This is fully explained in article 449, Chapter XVII.

391. Use of Stars, Planets, and Moon.—It may be judged that the employment in navigation of other heavenly bodies than the sun is considered of the utmost importance, and mariners are urged to familiarize themselves with the methods by which observations of stars, planets, and the moon may be utilized to reveal to them the position of their vessels at frequent intervals throughout the twenty-four hours.

It should be remembered, however, that in order to be of value these observations must be accurate; and to measure an accurate altitude of the body above the horizon it is required not only that the body be visible but also that the horizon be distinctly in view. Care should therefore be taken to make the observations, if possible, at the time when the horizon is plainest—that is, during morning and evening twilight. It may be urgently required to get a position during hours of darkness, and a dim horizon line may sometimes be seen and an observation taken, using the star telescope of the sextant; if the moon is shining, its light will be a material aid; but results obtained from such sights should be regarded as questionable and used with caution. Altitudes measured, however, just before sunrise and just after sunset are open to no such criticism; a fairly well-practiced observer who takes a series of sights at such a time, setting the sextant for equal intervals of altitude, will find the regularity of the corresponding time intervals such as to assure him of accuracy.

392. Identification of Unknown Bodies.—On account of the very great value to be derived from the use of stars and planets in navigation, it is strongly recommended that all navigators familiarize themselves with the names and positions of those fixed stars whose magnitude renders possible their employment for observations, and also with the general characteristics—magnitude and color—of the three planets (Venus, Jupiter, and Mars) which are most frequently used. A study of the different portions of the heavens, with the aid of any of the numerous charts and books which bear upon the subject, will enable the navigator to recognize the more important constellations and single stars by their situation with relation to each other and to the pole and the equator.

It may occur, however, that occasion will arise for observing a body whose name is not known, either because it has not been learned, or because the surrounding stars by which it is usually identified are obscured by clouds or rendered invisible by moonlight or daylight. In such a case the observer may estimate the hour angle and declination (the hour angle applied to local sidereal time giving the right ascension), and the star or planet may thus be recognized from a chart or from an inspection of the Nautical Almanac. This rough method will generally suffice when the body is the only one of its magnitude within an extensive region of the heavens; but cases often arise where a much closer approximation is necessary, and more exact data are required for identification.

393. If in doubt as to the name of the body at the time of taking the sight, it should be made an invariable rule to observe its bearing by compass, whence the true azimuth may be approximately deduced by applying the compass error.

Star Identification Tables giving simultaneous values of the declination and hour angle, corresponding to the values of the latitude, altitude, and azimuth ranging from 0° to 88° in latitude and altitude and from 0° to 180° in azimuth, are published by the Hydrographic Office for the convenience of navigators. In the absence of these Star Identification Tables, the following method affords a means of identification:

$$\sin d = \sin L \sin h + \cos L \cos h \cos Z \qquad (1)$$
$$\sin t = \sin Z \cos h \sec d \qquad (2)$$

Having computed the value of d, the declination, from (1), reckoning Z from the elevated pole of the observer and noting carefully the sign of cosine Z, the value of t, the hour angle, is computed from (2). In the catalogues and lists giving the names and magnitudes of the stars, they are tabulated by their declinations and right ascensions because these coordinates are independent of diurnal rotation, and, this being so, it becomes necessary, on finding the hour angle from (2), to convert it into right ascension; and then, with the values of the declination and right ascension thus found, to scan the list of stars and find the name of that one whose catalogued coordinates best agree with these values. The stars that are bright enough to be observed with nautical instruments are so far apart in the firmament that the identification will be complete if the computation be but roughly made. The possibility that the observed body may be a planet must always be kept in mind in scanning the star table or chart.

EXAMPLE: At sea, February 26, 1916, L. M. T. 6h 20m p. m. Weather overcast and cloudy. Observed the altitude of an unknown star through a break in the clouds to be 31° 30′ (true), bearing 285° (true). What is the name of the star? Ship's position, by D. R., latitude 35° 20′ N., longitude 60° W.

L	35° 20′	log sin	9.762	log cos	9.912		
h	31° 30′	log sin	9.718	log cos	9.931	log cos	9.931
Z	285° 00′ (N 75° W)			log cos	9.413	log sin	9.985
A	0.302	log...	9.480				
B	0.180			log...	9.256		

A+B = 0.302 + 0.180 = 0·482 = nat sin d ∴ d = 28° 49′... log sec 10.057

t=H. A.=70°=4h 40m.................. log sin 9.973

Then converting the hour angle into right ascension, as follows:

L. M. T.	$6^h\ 20^m$
R. A. M. S.	22 20
corr. for G. M. T.	+ 2
L. S. T.	4 42
H. A.	4 40
R. A.	0 02

The right ascension and declination of the unknown star, as we have now approximately found them, are $0^h\ 02^m$ and 28° 49′ N., respectively. The star is, therefore, α Andromedæ, whose tabulated coordinates are right ascension $0^h\ 04^m\ 02^s$ and declination 28° 37′ 36″ N.

394. Value of the Moon in Observations.—Next to the sun, the most conspicuous body in the heavens is the moon, and it may therefore frequently be employed by the mariner with advantage. Owing to its nearness to the earth and the rapidity with which it changes right ascension and declination, the various corrections entailed render observations of this body somewhat longer to work out, with consequent increased chances of error; and errors in certain parts of the work will have more serious results than with other bodies; the navigator will therefore usually pass the moon by if a choice of celestial bodies is offered for a determination of position; but so many occasions present themselves when there is no available substitute for the moon that the extra time and care necessary to devote to it are well repaid. During hours of daylight it is often clearly visible, and its line of position may cut with that of the sun at a favorable angle, giving a good fix from two observations taken at the same time, when the only other method of finding the position would be to take two sights of the sun separated by a time interval in which an imperfect allowance for the true run intervening would affect the accuracy of the result, or a clouding-over of the heavens would prevent any definite result whatever being reached; and during the night, the gleam upon the water directly below the moon may define the horizon and give opportunity for an altitude of that body when it is impossible to take an observation of any other. It has been the purpose of this work to point out the features of the various sights wherein the practice with the moon differs from that of the sun, stars, or planets; care and intelligent consideration will render these quite clear.

Besides its availability for determining Sumner lines of position, which it shares with other bodies, the moon affords a means for ascertaining the Greenwich mean time independently of the chronometer, thus rendering it possible to deduce the longitude and chronometer error. This is accomplished by the method of lunar distances.[1] If the Greenwich time given by an observation of lunar distance could be relied upon for accuracy, the method would be a great boon to the navigator; but this is not the case. The most practiced observer can not be sure of obtaining results as close as modern navigation demands, and the errors to which the method is subject are larger than the errors that may be expected in the chronometer, even when the instrument is only a moderately good one and its rate is carried forward from a long voyage. The method is not, therefore, recommended for. use except where the chronometer is disabled or where it is known to have acquired some extraordinary error; and when lunar distances are resorted to care must be taken to navigate with due allowance for possible inaccuracy of the results. In this connection it is appropriate to say that the best safeguard against the dire consequences that may result from a disabled or unreliable chronometer is for every vessel to carry two—or, far better, three—of those instruments, the advantages of which plan are stated in article 265, Chapter VIII.

395. Employment of Bodies dependent upon their Position.—The practical navigator will soon observe that there are certain conditions in which bodies are especially well adapted for the finding of latitude, and others where the longitude is obtained most readily.

Taking the sun for an example, when a vessel is on the equator and the declination is zero, that body will rise due east of the observer and continue on the same bearing until noon, when for an instant it will be directly overhead, with a true altitude of 90°, and will then change to a bearing of west, which it will maintain until its setting. In such a case any observation taken throughout the day will give a true north-and-south Sumner line, defining longitude perfectly, but giving no determination of the latitude, excepting for a moment only when the body is on the meridian. With the exception noted, all efforts to determine the latitude will fail. The reduction to the meridian takes the form $\frac{0}{0}$, becoming indeterminate, and in the ϕ' ϕ'' sight the cosine of ϕ' will assume a value that corresponds alike to any angle within certain wide limits—the limits within which the circle of equal altitude has practically a north-and-south direction. In conditions approximating to this we may obtain a longitude position more easily than one for latitude, even within a few minutes of noon.

[1] The tables of lunar distances have been omitted from the American Ephemeris and Nautical Almanac after the volume for the year 1911.

As the latitude and declination separate, conditions become more favorable for finding latitude and less so for longitude; the intermediate cases cover a wide range, wherein longitude may be well determined by observations three to five hours from the meridian, and latitude by those within two hours of meridian passage. As extreme conditions are approached the accuracy of longitude determinations continues to decrease; at a point in 60° north latitude, when the sun is near the southern solstice, its bearing differs only 39° from the meridian at rising; or, in other words, even if observed at the most favorable position, the resulting Sumner line is such that 1′ in latitude makes a difference of 1.3 miles of departure, or 2′.6 of longitude, and is far better for a latitude determination than for longitude. And in higher latitudes still this condition is even more marked.

Having grasped these general facts, the navigator must adapt his time for taking sights to the circumstances that prevail, and when the sun does not serve for an accurate determination of either latitude or longitude the ability to utilize the stars, planets, and moon as a substitute will be of the greatest advantage.

396. Use of Various Sights.—Except when employing the method of Saint Hilaire (Chapter XV), the navigator may sometimes be in doubt as to the best method of working a sight. No rigorous rules can be laid down, and experience alone must be his guide. In a general way it may be well, when the body is nearer to the prime vertical than to the meridian, to work it for longitude, assuming latitude, and using the time sight; and when nearer the meridian to work it for latitude, assuming longitude, by the ϕ' ϕ'' method. The time sight is more generally used than the other, it has wider limits of accurate application and is probably a little quicker; but as the meridian is approached and the hour angle decreases small errors in the terms make large ones in the results. The ϕ' ϕ'' or latitude method should not ordinarily be employed beyond three hours from the meridian, and then only when the body is within 45° of azimuth from the meridian and has a declination of at least 3°; with an hour angle of 6^h (90°) or a declination of 0° the trigonometric functions assume such form that the method is not available; nor does it give definite results when the azimuth is 90° or thereabouts.

When the body is close enough to the meridian for the method of reduction to the meridian to be applicable, that method is to be preferred because of its quickness and facility. It should be noted, however, that, though close enough to employ the reduction, it may not be sufficiently correct to assume that the body bears due north or south, and the sight should be worked with two longitudes, or the Sumner line determined by the azimuth, unless the bearing nearly coincides with the direction of the meridian.

397. Working to Seconds and Accuracy of Determinations.—The beginner who seeks counsel from the more experienced in matters pertaining to navigation will find that he receives conflicting advice as to whether it is more expedient to carry out the terms to seconds of arc, or to disregard seconds and work with the nearest whole minute.

It is a well-recognized fact that exact results are not attainable in navigation at sea; the chronometer error, sextant error, error of refraction, and error of observation are all uncertain; it is impossible to make absolutely correct allowance for them, and the uncertainty increases if the position is obtained by two observations taken at different times, in which case an exactly correct allowance for the intervening run of the ship is an essential to the correctness of the determination. No navigator should ever assume that his position is not liable to be in error to some extent, the precise amount depending upon various factors, such as the age of the chronometer rate, the quality of the various instruments, the reliability of the observer, and the conditions at the time the sight was taken; perhaps a fair allowance for this possible error, under favorable circumstances, will be 2 miles; therefore, instead of plotting a position upon the chart, and proceeding with absolute confidence in the belief that the ship's position is on the exact point, one may describe, around the point as a center, a circle whose radius is 2 miles—if we accept that as the value of the possible error—and shape the future courses with the knowledge that the ship's position may be anywhere within the circle.

It is on account of this recognized inexactness of the determination of position that some navigators assume that the odd seconds may be neglected in dealing with the different terms of a sight; the average possible error due to this course is probably about one minute, though under certain conditions it may be considerably more. It is possible that, in a particular case, the error thus introduced through one term would be offset by that from others, and the result would be the same as if the seconds had been taken into account; but that does not affect the general fact that the neglect of seconds as a regular thing renders any determination liable to be in error about one minute. Those that omit the seconds argue, however, that since, in the nature of things, any sight may be in error two minutes, it is immaterial if we introduce an additional possibility of error of one minute, because the new error is as liable to decrease the old one as to increase it; but the fallacy of the argument will be apparent when we return to the circle drawn around our plotted point. The eccentricity of the sextant may exactly offset the improper allowance for refraction, and the mistake in the chronometer error may offset the observer's personal error, but unless we know that such is the case—which we never can—we have no justification for doing otherwise than assume that the ship may be any place within the 2-mile circle. If, now, we increase the possible error by 1 mile, our radius of uncertainty must be increased to 3 miles, and the diameter of the circle, representing the range of uncertainty in any given direction, is thereby increased from 4 to 6 miles.

It is deemed to be the duty of the navigator to put forth every effort to obtain the *most probable* position of the ship, which requires that he shall eliminate possible errors as completely as it lies within his power to do. By neglecting seconds he introduces a source of error that might with small trouble be avoided. This becomes of still more importance since modern instruments and modern methods constantly tend to decrease the probability of error in the observation, and to place it within the power of the navigator to determine his ship's position with greater accuracy.

398. There is a more exact way of defining the area of the ship's possible position than that of describing a circle around the most probable point, as mentioned in the preceding article, and that is to draw a line on each side of each of the Sumner lines by which the position is defined, and at a uniform distance therefrom equal to the possible error that the navigator believes it most reasonable to assume under existing conditions; the parallelogram formed by these four auxiliary lines marks the limit to be assigned for the ship's position: this method takes account of the errors due to poor intersections, and warns the navigator of the direction in which his position is least clearly fixed and in which he must therefore make extra allowance for the uncertainty of his determination.

It must be remembered in this connection that no position can ever be obtained, when out of sight of the land, except from the intersection of two Sumner lines, whether or not the lines are actually plotted; thus, a meridian altitude gives a Sumner line that extends due east and west, and a sight on the prime vertical a line that extends north and south, though it may not have been considered necessary to work the former with two longitudes or the latter with two latitudes.

399. THE WORK BOOK AND FORMS FOR SIGHTS.—The navigation work book, or sight book, being the official record of all that pertains to the navigation of the ship when not running by bearings of the land, should be neatly and legibly kept, so that it will be intelligible not only to the person who performed the work, but also to any other who may have reason to refer to it.

Each day's work should be begun on a new page, the date set forth clearly at the top, and preferably, also, a brief statement of the voyage upon which the ship is engaged. It is a good plan to have the dead reckoning begin the space allotted for the day, and then have the sights follow in the order in which taken. The page should be large enough to permit the whole of any one sight to be contained thereon without the necessity of carrying it forward to a second page. No work should be commenced at the bottom of a page if there is not room to complete it. Every operation pertaining to the working of the sights should appear in the book, and all irrelevant matter should be excluded.

It is well to observe a systematic form of work for each sight, always writing the different terms in the same position on the page; this practice will conduce to rapidity and lessen the chances of error. In order to facilitate the adoption of such a method, there are appended to this work (Appendix II) a series of forms that are recommended for dead reckoning, and for the various sights of the sun, stars, planets, and moon, respectively. For beginners, these are deemed of especial importance, and it is recommended that, until perfect familiarity with the different sights is acquired, the first step in working out an observation be to write down a copy of the appropriate blank form, indicating the proper sign of application of each quantity (for which the notes will be a guide), and not to put in any figures until the scheme has been completely outlined; then the remainder of the work will consist in writing down the various quantities in their proper places and performing the operations indicated.

The navigator may make up his work book by having printed forms of the various sights which can be placed in a loose-leaf binder when they have been filled in with his computations. Instead of printed forms on separate sheets, he may employ rubber stamps of the various forms of sights which he may stamp in his work book or on loose leaves.

THE SPECIFIC STEPS FOR CARRYING OUT THE DAY'S WORK.

400. The day's work as described herein is so laid out that the true position at noon is known some few minutes before noon, as, when cruising in company, naval vessels have to make their noon position report by signal at exactly 12 o'clock. When cruising singly the noon position need not be known until after 12 o'clock, but it is advisable to do a day's work always in one way, and, therefore, the plan of getting the correct noon position before noon will be followed.

401. The Time to Take an A. M. Observation.—The navigator of a vessel cruising may, by dead reckoning or by plotting on a chart, predict the approximate position of the ship the following morning, and from that position may easily determine the best time to observe the sun (or other body) for longitude. Having determined his approximate 8 a. m. position, he takes from the Nautical Almanac the declination of the sun for Greenwich noon of that day. With the latitude of the 8 a. m. position and declination for the day, he enters the Azimuth Tables and takes out the local apparent time when the sun will bear 90°. By getting the error of his watch on local apparent time for the approximate 8 a. m. longitude, he may easily find the watch time when the sun will bear 90°, which is the time he should take his sight. Suppose on the evening of July 18, 1916, a navigator finds that at 8 a. m. *the next day* he will be in approximate Lat. 35° 12′ N., Long. 65° 15′ W., and wishes to find at what time *by his watch* the sun will be on the prime vertical. He compares his watch with the chronometer, of which he knows the correction, and which is, we will say, slow $1^m\ 10^s$ on G. M. T., and finds that when the chronometer reads, say $11^h\ 59^m\ 30^s$, the watch reads $7^h\ 15^m\ 12^s$. He then does the following work:

He takes from the Nautical Almanac the declination and the equation of time for Greenwich mean noon on July 19 and finds Dec.=20° 52′ N.; Eq. t. $6^m\ 04^s$, subtractive from mean time.

With Lat. 35°.2 N., Dec. 21°.0 N., enter the Azimuth Tables, and find, for a bearing of 90°, the L. A. T. is about $8^h\ 10^m$

Write down the reading of the chronometer face at comparison		11^h	59^m	30^s
Apply the chronometer correction	+		1	10
G. M. T. of the time of comparison		12	00	40
Apply equation of time	−		6	04
Greenwich apparent time of comparison		11	54	36
For Long. 65° 15′ W., $\lambda=4^h\ 21^m\ 00^s$. Apply λ		4	21	00
At time of comparison the L. A. T. at the 8 a. m. position was		7	33	36
At time of comparison the watch time was		7	15	12
Error of watch on L. A. T. of 8 a. m. position			18	24 slow.
L. A. T. when sun is on prime vertical		8	10	
Watch time to take a. m. observation		7	51	36

The observation should therefore be taken when the watch face reads about 7–52, which will bring the sun very close to the prime vertical.

When the latitude and declination are of different names the sun crosses the prime vertical before rising. In that case, the observation is taken as soon as the sun is sufficiently high to be unaffected by any peculiar condition of the atmosphere, usually about an hour after sunrise. The L. A. T. of sunrise and sunset is given at the bottom of the page in the Azimuth Tables. Suppose in the above example the approximate 8 a. m. latitude was 35°.2 S. instead of 35°.2 N. Entering the tables with Lat. and Dec. of different names, we find the time of sunrise is about 7 a. m. The observation should therefore be taken at about 8 a. m. L. A. T., the watch time of which can be found in the same way as explained above.

In a similar manner Azimuth Tables may be used to find the best time to take p. m. observations for longitude.

402. The Morning Work of the Navigator.—The navigator, having determined the time at which he will take his morning observation, is called sufficiently early to be ready for work about 15 minutes before the time chosen.

The first thing the navigator does is to check up his time. To save the trouble of going below to compare the watch with the standard chronometer each time that an observation is taken, most navigators keep the hack chronometer in the chart house and use it for comparisons during the day. It is necessary to check the hack with the standard chronometer each day to make sure of its error on G. M. T. and rate. This comparison is made the first thing in the morning, the date, the error on G. M. T., and the rate of the hack being written on a slip of paper that is placed in the hack case. The hack is then taken to the chart house and is used for the day's work. As hack chronometers frequently have high daily rates, an additional correction sometimes has to be made for the rate when observations have been taken some hours after the comparison. The hack is sometimes used for marking the time of observation, and. when so used. the G. M. T. is at once obtained by applying the hack error.

Having checked up the hack chronometer, the navigator then prepares his sextant and takes it, with his watch and notebook, to the place from which he takes his observations. At about the time he has selected for his purpose, he observes altitudes of the sun, which, with the corresponding watch times are noted in his notebook. The patent log is read while the observations are being taken and the reading is entered in the notebook. The navigator then goes to the standard compass and gets a bearing of the sun, which with the watch time of the bearing and the compass heading of the ship is entered in the notebook. Either just before or just after observing the altitude of the sun with the sextant, the index correction should be found and entered in the notebook. The navigator next compares his watch with the hack chronometer and gets the C-W, which is also entered in the notebook. From the log book he gets the courses and distances run from the last "fix" and enters them in his notebook. This completes the data for his morning's work.

The computations are then made in the navigator's work book. The first step is to work up the dead reckoning from the last "fix" to the time of sight. It may be well here to call the attention of the student to the fact that for "distance run" the propellers frequently are a more accurate gauge than the patent log which sometimes gets foul. In a smooth sea the distance by revolutions is usually very accurate, especially if the effect of the condition of the bottom as to fouling is known. In heavy weather the patent log is a better gauge as the effects of the wind and sea on the speed of the ship are hard to determine. But for distance run both the patent log and revolutions should be considered, and, if there is a discrepancy between them, it should be investigated and the more accurate distance should be used.

Having brought the dead reckoning up to the time of sight, the latitude so found is taken as the base of the computation of the longitude by observation. It is assumed that the student is familiar with the various methods of getting a line of position from an observation. Any one of the various methods gives the same line and the choice of method is naturally the choice of the individual.

Having obtained the line of position, the longitude factor is next found, as explained in article 387. The longitude factor is used twice, first to find the longitude by observation corresponding to the D. R. latitude, and again after the noon latitude is determined, to find the true noon longitude. As soon as the longitude factor has been obtained, the longitude by observation corresponding to the D. R. latitude is found, and it is this point on the line of position that is used for the rest of the work to noon. This point, corrected for run, is also the point adopted as the 8 a. m. position, and as by using it future steps are simplified, it is advisable always to work from this point. Of course, any other point on the line can be moved up, and the final result will be the same, but the computation will be a little more complicated.

Having obtained the position at time of sight (D. R. Lat., Long. by obs.) and the longitude factor, the navigator next proceeds to get the compass error. The work he has already performed in getting the line of position gives him certain data that will shorten his work in finding the compass error. If the sight has been worked out as a Sumner line the navigator, by taking the L. A. T. found by his computation and correcting it for the difference between the watch times of his observation for altitude and observation for azimuth, may obtain at once the L. A. T. of the time at which he took the sun's azimuth. With this L. A. T., and the Lat. and Dec. used in working out his sight, he may at once find from the Azimuth Tables the true bearing of the sun and get the compass error. If the line of position has been obtained by one of the tangent methods, the navigator has, in his computation, determined the true bearing of the sun at the time of sight. All he has to do to get the true azimuth for compass error is to correct this bearing for the change in azimuth due to the difference in time between his observation for altitude and his observation for azimuth. This correction is easily found from the Azimuth Tables by inspection.

This completes the morning work when the amount of work each day is a minimum. When very accurate positions are required at other times than at noon, as for instance, when a vessel is scouting, when in dangerous waters, moving at high speed, or when making a landfall, other lines of position are worked out, and the ship's position found on each line by moving the next preceding line up to it for run. For instance, lines obtained from morning twilight sights of the moon, stars, or planets, may be run up to the 8 a. m. line, the 8 a. m. line may be run up to one taken at 9.30 or 10, or later, and so on. When getting the position by the intersection of lines moved up for run, it is usual to perform the work on the plotting charts supplied for this particular purpose. These charts are Mercator projections covering each 5° of latitude from 0° to 60°. The parallels are numbered for every degree of latitude, and the navigator selects the chart covering the latitude in which he is working. The meridians on these charts, not being numbered, the navigator is left free to mark them with the longitudes through which he is working. The charts are of large scale, and, being on heavy paper, may be used over and over, lines on these being drawn in lightly and erased when no longer required.

Intersections of lines of position may be computed, as explained in Chap. XV, when there are no charts at hand suitable for plotting the lines graphically. Special plotting sheets prepared by the United States Hydrographic Office are supplied to vessels of the Navy.

403. THE WORK BETWEEN 11 A. M. AND NOON.—Two important steps, not usually fully explained in the text books, must be studied. These are: *First,* to determine the exact run from the time of the a. m. sight to local apparent noon; *second,* to set the watches and clocks to the local apparent time of the place the ship will be at local apparent noon.

If the ship has been making westing, the watches and clocks will be ahead of the local apparent time of the noon position and will have to be set back by the amount of the change in longitude. As the change of time is made between 11 a. m. and noon, it will be seen that the elapsed time between the time of the a. m. sight and the new watch time of noon will be more than the watch face shows by the amount the watch has been set back, and this difference must be allowed for in computing the run to noon. In the same way, if the ship has been making easting, the clocks and watches will have to be set ahead and the elapsed time between the time of the a. m. sight and the new watch time of noon will be less than the watch face shows by the amount the watch has been set ahead, and must be allowed for in computing the run to noon. It must be remembered that this time can not be computed exactly, but it can be approximated very closely in this way. Suppose a ship has been steaming on course 66° true, and the navigator finds from his a. m. observation taken at watch time, $8^h\ 00^m\ 03^s.5$, that the L. A. T. for the position, Lat. by D. R. 38° 03′.2 N., Long. by obs. 72° 50′ 26″ W., is $8^h\ 17^m\ 23^s.9$. He sees at once that at 8 a. m. his watch is already slow $17^m\ 20^s.4$ on L. A. T. Now, if he continues on this course 66° true, at a speed of 11.7 knots per hour, the watch will be still slower at noon. He therefore turns to the Traverse Tables and finds that on that course and at a speed of 11.7 knots the ship will each hour go 10.69 miles to the eastward, which, in Lat. 38°, makes a change of longitude of 13′.6 each hour. Now, from time of sight to 11 a. m. the change of longitude will be $3 \times 13'.6 = 40'.8$ of longitude, which is equal to a further loss of $2^m\ 43^s.2$ of time; but the watch was already slow $17^m\ 20^s.4$, so that at 11 a. m. the watch will be slow $20^m\ 03^s.6$, and the time to noon will be $1^h - (20^m\ 04^s)$, the difference due to change in longitude in $39^m\ 56^s\ (1^h - 20^m\ 04^s)$. Now $39^m\ 56^s = 0.66^h$ and the change of longitude $= 0.66 \times 13'.6 = 9'.0$ of long. $= 36^s.0$ of time. Hence the total amount the time will be changed will be:

Change to time of a. m. sight	17^m	$20^s.4$
Change between a. m. sight and 11 a. m	2	43.2
Change between 11 a. m. and L. A. noon	0	36.0
Total change	20	39.6

and the run to noon will be four hrs. minus this change $= 3^h\ 39^m\ 20^s.4 = 3.66$ hrs. The distance run to noon will be $3.66^h \times 11^{kts}.7 = 42^{kts}.8$.

The navigator can now run the a. m. point, determined by dead reckoning latitude and longitude by observation, up to noon, and, after that he is ready to set his watch and clocks to the time of the coming local apparent noon position.

404. If the body observed for the a. m. sight was on or near the prime vertical, the longitude found from it would be correct for the time of observation, since an error in latitude makes no change in the longitude. This longitude when compared with the longitude by dead reckoning at the time of sight will show if there has been an easterly or westerly set of the current, and the amount of it. If a current is found and allowed for, for the time of the run from time of sight to noon, the noon longitude can be found very accurately. If the heavenly body used for the a. m. observation was not near the prime vertical, the exact easterly or westerly set can not be determined; but a close approximation to it can generally be made by comparing the longitude found by observation with the D. R. longitude, and the current so found should be allowed for in running the a. m. point up to noon. The error will be small and will give results sufficiently accurate for ordinary work. Having allowed for easterly or westerly current and having run the a. m. position point by observation up to noon, the navigator can then set his watch to local apparent time of the noon position, and his watch can be used to set the deck clocks. A convenient way to set the watch is as follows: Having looked at the hack face and found what it reads, say $4^h\ 09^m\ 50^s$, let it be determined to set the watch to the correct local apparent time of the noon position when the hack face reads $4^h\ 15^m\ 00^s$.

Write down reading of hack face at time watch is to be set	4^h	15^m	00^s
Apply the hack correction (in this case hack is $5^m\ 38^s$ fast on G. M. T.)	(−)	5	38
This gives G. M. T. at which watch is to be set to L. A. T	4	09	22
Apply equation of time corrected for longitude of noon position	(+)	11	33.8
This gives G. A. T. of time watch is to be set	4	20	55.8
Now apply longitude for noon position (in this case)	4	48	23
Watch face should read	11	32	32.8

The watch is now to be set so that, at $4^h\ 15^m\ 00^s$ by hack, the watch face will show as near $11^h\ 32^m\ 33^s$ as possible. It will be found, since the second hand of a watch can not be set, that the watch can not be set to the exact reading. By care, however, the watch can be set so that it will be 30 seconds or less fast or slow on the desired time. The number of seconds the watch is fast or slow on L. A. T. should be noted in the work book, as it will be a help in taking near-noon sights to get the correct L. A. T. at once from the reading of the watch face instead of comparing the watch again with the chronometer. The watch being set as nearly as possible to the correct L. A. T. and the error being recorded, the deck clocks are set; and the navigator then proceeds to work up his constants for his near-noon observations for latitude, and completes all his forms and fills them out as far as possible before taking the observations.

405. Now suppose the navigator wishes to take his observations at 15, 10, and 5 minutes before local apparent noon and desires to get constants for these times to which he can apply his sextant altitudes and at once get his correct noon latitude. To find the watch times at which he should take these observations, he must know the error of his watch on local apparent time of the place of observation. He knows the error of his watch on the L. A. T. of the noon position (in this case we will suppose the watch is 18^s fast). He knows that on course 66° true, speed 11.7 knots, in Lat. 38°, that in 1 hour he changes longitude 13′.6. Therefore 15 minutes before noon the ship will be 3′.4 of longitude west of where it will be at noon = $13^s.6$ of time. Hence the observation 15 minutes before noon should be taken at watch time $11^h\ 45^m\ 00^s + 18^s$ (= amount watch is fast on L. A. T. of noon position) + $13^s.6$ (= amount watch is fast on L. A. T. of place of first near-noon observation) = $11^h\ 45^m\ 31^s.6$. Similarly the observation taken 10^m before noon should be taken at watch time $11^h\ 50^m\ 00^s + 18^s + 9^s.1$ (= amount watch is fast on L. A. T. of place of second observation) = $11^h\ 50^m\ 27^s.1$. The observation taken 5 minutes before noon should be taken at watch time $11^h\ 55^m\ 00^s + 18^s + 4^s.5$ (= amount watch is fast on L. A. T. of place of third observation) = $11^h\ 55^m\ 22^s.5$. A meridian altitude would of course be taken at watch time $12^h\ 00^m\ 18^s$.

Having obtained the watch times of the observations, the navigator next works out the constants. These constants are obtained in the same way as meridian altitude constants but to each are applied two corrections to the meridian altitude constant. These are:

(1) at^2 or the correction to be applied to an observed altitude near noon to make it a meridian altitude.

(2) ΔL or the difference in latitude for the run from the time of observation to noon.

In working out the constant, the method of obtaining a meridian altitude constant is followed and the two corrections mentioned above are applied to it. In getting a meridian altitude constant, one has first to ascertain the approximate altitude. If the student will in every case plot his elements roughly on the plane of the meridian, putting O, the observer, at the center, a horizontal line through the O with the right end marked S for south, and the left end N for north, to represent the horizon, and draw a vertical line upward from O (marking its intersection with the circle Z) to represent the zenith, he can by inspection write out his formulæ and see exactly how to apply all corrections. A few minutes' study will make this method clear and will fully repay the very slight mental effort required to master it.

Now suppose L is the latitude of the noon position and L′ the latitude of the point from which the near-noon observation was taken. Then $L = L' \pm \Delta L$ where ΔL is the change in latitude from the time of observation to noon.

Suppose, by inspection of the figure we have drawn, we see that for a meridian altitude,

$$L' = 90° - d - \text{obs. alt.} \pm \text{corr. to alt.}$$

Now when the observed altitude is taken before noon the correction at^2 has to be applied to it to bring it to what the meridian altitude would be. Therefore, for an altitude taken before noon,

$$\begin{aligned} L' &= 90° - d - (\text{obs. alt.} + at^2) \pm \text{corr. to alt.} \\ &= 90° - d - \text{obs. alt.} - at^2 \pm \text{corr.} \\ L &= 90° - d - \text{obs. alt.} - at^2 \pm \text{corr.} \pm \Delta L. \\ &= K - \text{obs. alt.} \\ \text{or } K &= 90° - d - at^2 \pm \text{corr.} \pm \Delta L. \end{aligned}$$

Having the watch time at which the near-noon observation is taken and K corresponding to it, it is only necessary to apply the observed altitude to its proper K to get the correct noon latitude. Having the *correct* noon latitude, find by how many minutes it differs from the D. R. noon latitude and multiply this difference by the longitude factor to get the correction to be applied to the 8.00 a. m. longitude by observation run up to noon, in order to get the correct noon longitude. This part of the work is done roughly on deck in the navigator's note book as soon as the altitude is taken. To facilitate this work the navigator writes his data in his note book in the following form, filling the blank spaces after getting his altitude:

For watch time	11h 45m 30s	11h 50m 26s	11h 55m 22s	12h 00m 18s
K	84 54 44	84 59 03	85 01 29	85 02 02
Obs. Alt.				
Noon Lat. by Obs.				
Mean				
Noon Lat. by D. R.	38° 20′ 35″			
D L				
Long. factor (Tab. 47)	.65			
Corr. in Long.				
Noon Long. by a. m. Obs.	72° 05′ 44″			
True longitude at noon				

406. Having obtained the correct noon position in the above manner, the navigator completes his work in his work book and plots the ship's position on the chart. Having the correct noon position, he compares it with his previous noon position (or point of departure) and gets the true course and distance made good. Having the position by dead reckoning and by observation, he gets the set and drift of the current. He then computes the total distance gone since leaving port and the distance yet to go to his destination. Blank forms for the noon report are arranged for the following data:

(1) Lat. by observation.
(2) Long. by observation.
(3) Lat. by D. R.
(4) Long. by D. R.
(5) Current: Set and Drift.
(6) Course made good.
(7) Distance made good since noon.
(8) Distance made good since departure.
(9) Distance to destination.

If the course sailed is a rhumb line, and the ship is practically on the line laid out as the track, no change of course is necessary. If the ship is decidedly off the rhumb line course as laid out, or is sailing on a great circle track that requires a change in compass course, the new course is laid out as soon as the true noon position is obtained. This completes the navigator's work to noon.

407. The Afternoon Work of the Navigator.—In the afternoon the navigator must take an observation for longitude. He selects a time when the sun is as near as possible to the prime vertical, which time is determined in the same way as explained for the a. m. observation. He runs his true noon position up to the time of his p. m. observation, making an allowance for any evident current that was found at noon. He then gets a position point on a line of position determined from his observation. This point is run up to 8 p. m. by dead reckoning, which position is plotted on the chart and completes the minimum navigation work for any day.

When particularly accurate positions are required, especially at 8 p. m., the navigator takes an additional observation of the sun, or of some other heavenly body at twilight, and gets the intersection of two lines of position. Or he may get a line for longitude and a line for latitude by an altitude of Polaris or another star. In this way the navigator may, at either morning or evening twilight, get a very accurate fix; and this is done frequently. In fact, fixes obtained from observations of two heavenly bodies taken at about the same time are the most accurate fixes that can be obtained at sea, as the intersection of the two lines of position give a position point that is correct at the time, no matter what the current is. Careful navigators will therefore take such observations and the student should prepare himself to do so. The methods of using position points obtained in this way are exactly the same as the methods of using the points already explained.

The following example will give a good idea of the minimum day's work for the navigator at sea. The form laid out is one that can always be followed. The cosine-haversine formula is used for getting the lines of position, but any other method may be substituted for it.

EXAMPLE: On October 4, 1916, the U. S. S. *Delaware* left Hampton Roads for Lisbon. From the Chesapeake Capes the great circle course was followed. The distance to Lisbon by great circle course is 3,120 miles. It is 25 miles from Hampton Roads to the point from which the departure was taken. At 5 p. m., with Cape Henry Light bearing 301° (mag.), dist. 8.3 miles, took departure, set course 74° (p. s. c.) (Var. 5° W., Dev. 3° W.), and put over patent log, reading 0. (The point of departure is Lat. 36° 51′ 59″ N., Long. 75° 51′ 03″ W.)

The next morning by comparison with the standard, the hack chronometer was found to be $5^m\ 38^s$ fast on G. M. T. and gaining $1^s.5$ daily. At about 8 a. m., patent log, reading 175.0, the navigator took an a. m. observation for longitude: W. T. $8^h\ 00^m\ 03^s.5$; obs. alt. 22° 55′ 10″; I. C. + 1′ 50″; ht. of eye 40 ft. The navigator then observed an azimuth of the sun as follows: W. T. $8^h\ 02^m\ 29^s$; bearing of sun p. s. c. 125° 30′; ship's head 74°. He then compared his watch with the hack as follows: hack face $1^h\ 13^m\ 00^s$; watch face $8^h\ 10^m\ 11^s$.

Perform the a. m. part of the day's work.

The ship continues on same course at same speed (11.7 knots). When the hack face reads $4^h\ 15^m\ 00^s$, at what time should the watch be set to be on local apparent time at the noon position?

If the watch was set 18 seconds fast on local apparent time at the noon position, work out constants for observations for latitude to be taken 15, 10, and 5 minutes before noon and at noon. Prepare all forms for the noon work.

The observed altitudes near noon were as follows: 15 minutes before, 46° 12′ 30″; 10 min. before, 46° 16′ 50″; 5 min. before, 46° 19′ 20″. The noon alt. was 46° 19′ 40″. The patent log read 217.5 at noon.

Complete the day's work for noon.

At noon the course was changed to 86° (p. s. c.), Var. 10° W., Dev. 4° W. Steamed until 4 p. m. on this course, when at W. T. $4^h\ 00^m\ 12^s$, obs. alt. of sun 18° 32′ 40″; C − W, $4^h\ 40^m\ 56^s$; I. C., + 1′ 50″; ht. of eye, 40 ft.; patent log reading, 264.3.

Find position of ship at 4 p. m. by observation.

The course and speed remaining unchanged, find the 8 p. m. position.

October 5, 1916.—A. M. Work.

D. R. from point of departure to time of a. m. observation:

Course.	Var.	Dev.	Comp. error.	True course.	Dist.	N.	E.	D. Lo.
74° (p. s. c.)	5° W.	3° W.	8° W.	66°	175.0	71′.2	159.9	201′.4 E.

Point of departure:	Lat.	36° 51′ 59″ N.	Long.	75° 51′ 03″ W.
	D. L.	1 11 12 N.	D. Lo.	3 21 24 E.
D. R. position 8 a. m.:	Lat.	38 03 11 N.	Long.	72 29 39 W. λ=4^h 49^m 58^s.6

A. M. Sights of ⊙

C. T.	1^h 13^m 00^s	Obs. alt. ⊙	22° 55′ 10″	(Tab. 46)	+7′ 42″	Dec.	4° 42′.7 S.	H. D.	−1′.0	Eq. t.	11^m 30^s.4	H. D.	+0^s.7
W. T.	8 10 11	Corr. +	9 32	I. C.	+1 50	Corr. −	.95	G. M. T.	.954^h	Corr. +	0 .7	G. M. T.	.954^h
C−W.	5 02 49	h	23 04 42	Corr.	+9 32	d	4° 43′ 39″ S.	Corr.	−0′.954	Eq. t.	11 31.1	Corr.	+0^s.667
W. T.	8 00 03.5									(*Add* to *mean* time.)			
				t	3^h 41^m 13^s	log hav	9.33323						
C. T.	1 02 52.5			L	38° 03′ 11″ N.	log cos	9.89622						
C. C.	− 5 38.0			d	4 43 39 S.	log cos	9.99852						
G. M. T.	0 57 14.5=0.954 hrs. on Oct. 5, 1916.			θ		log hav	9.22797	nat hav	.16903				
Eq. t.	+ 11 31.1			L∼d	42 46 50			nat hav	.13302				
G. A. T.	1 08 45.6			z	66 40 40			nat hav	.30205				
λ	4 49 58.6	Calculated h			23 19 20								
L. A. T.	8 18 47	Observed h			23 04 42								
t	3 41 13	Alt. diff.			14 38=14.6 on reverse bearing of sun.								

From Azimuth Tables: With Lat. 38° N., Dec. 5° S., & L. A. T. $8^h\ 20^m$, sun bears N. 117° 15′ E.

NOTE.—[By using Weir's Azimuth Diagram the true bearing of the sun may be obtained without using the Azimuth Tables.]

Corr. for Dec. 4°.7 S=.3×46	=	−0° 14′	
Corr. for L. A. T. $8^h\ 18^m.8$=.12×113	=	−0 14	
Corr. for Lat. 38°.05=.05×23	=	+0 01	
Total correction		−0 27	− 0 27
True bearing of sun at time of sight			116 48
Reverse bearing of sun			296 48

With distance, 14′.6 (alt. diff.), on course=reverse bearing of sun.

True course	Dist.	N.	W.	D. Lo.
296°.8	14.6	6′.6	13.0	16′.5 W.

Lat. by D. R.	38° 03′ 11″ N.	Long.	72° 29′ 39″ W.
D. L.	6 36 N.	D. Lo.	16 30 W.
Position point to be used if line is plotted Lat.	38 09 47 N.	Long.	72 46 09 W.
Corr. to Long. to make it correspond to D. R. Lat.			4 17 W.
At 8 a. m. for D. R. Lat.	38 03 11 N.	Long.	72 50 26 W.
		λ	$4^h\ 51^m\ 21^s.7$

From Table 47, Long. factor .65
Diff. in Lat. 6′.6

Corr. in Long. 4′.29 W.=4′ 17″ W.

W. T. of a. m. sight	$8^h\ 00^m\ 03^s.5$	Sun's true bearing at time of a. m. sight.	116° 48′
W. T. of sun's compass bearing	8 02 29 .0	Change in azimuth for $2^m.43$ from azimuth tables	+ 0 28
Diff. in time	{2 25 .5 / 2^m. 43}	Sun's true bearing at time of compass bearing	117 16
		Observed compass bearing of sun	125 30
		Compass error	8 14 W.
		Variation by chart	5 00 W.
		Deviation of compass on ship's head 74° (p. s. c.)	3 14 W.

At a. m. observation the G. A. T. was	$1^h\ 08^m\ 45^s.6$	Long. at 8 a. m. by Obs.	72° 50′ 26″ W.
At a. m. observation the Long. by Obs. was	4 51 21 . 7	Long. at 8 a. m. by D. R.	72 29 39
At a. m. observation the L. A. T. was	8 17 23 . 9	Diff. in Long. due to current	20 47 =20′. 8 W.
At a. m. observation the W. T. was	8 00 03 . 5	Drift per hr. in Long.	$\frac{20.8}{15^h}$ = 1′. 39
At a. m. observation the watch was	17 20 . 4 slow on L. A. T.		

October 5, 1916.—Work from 11 a. m. to noon.

On course 66° (true), at speed 11.7 knots: Northing per hour=4.76. Easting per hour=10.69. D. Lo. per hour=13′.6.

Change in Long. per hour due to speed of ship	13′.6 E.	Change in Long. from 8 to 11 a. m.=12′.21×3ʰ=36′.63	2ᵐ 26ˢ.5
Change in Long. per hour due to current	1.39 W.	Watch slow on L. A. T. at 8 a. m.	17 20.4
Ship changes Long. per hour	12.21 E.	At 11 a. m. watch is slow on L. A. T	19 46.9
∴ time to noon={1ʰ−(19ᵐ 46ˢ.9)}=40ᵐ 13ˢ.1=0ʰ.67.			
Change in Long. from 11 to 12=.67×12′.21=8′.2=0ᵐ 32ˢ.8.			0 32.8
		Total amount watch will be set ahead	20 19.7

∴ Time of run from 8 a. m. to noon will be 20ᵐ 19ˢ.7 less than 4ʰ=3ʰ 39ᵐ 40ˢ.3=3ʰ.66.

Change in Lat. from 8 a. m. to noon=3ʰ.66×4′.76=17′.4. N. Change in Long. 3ʰ.66×12.21=44′.7. E.

At 8 a. m.: Lat. by D. R.	38° 03′ 11″ N.;	Long. by D. R.	72° 29′ 39″ W.;	Long. by Obs.	72° 50′ 26″ W.		
Run to noon D. L.	17 24 N.	D. Lo.	44 42 E.	D. Lo.	44 42 E.		
At noon: Lat. by D. R.	38 20 35 N.	Long. by D. R.	71 44 57 W.	8 a. m. Long. run to noon	72 05 44 W.	G. A. T.	4ʰ 48ᵐ 23ˢ
				λ=4ʰ 48ᵐ 23ˢ		Eq. t.	− 11 34
				(Used in Noon. Lat. Obs.)		G. M. T.	4 36 49

Set watch to L. A. T. when C. T.	4ʰ 15ᵐ 00ˢ	Dec. 4ʰ	4° 46′.5 S.	H. D.	−1′.0	Eq. t. 4ʰ	11ᵐ 33ˢ.4	H. D.	+ 0ˢ.7
		Corr.	− 0.6	G. M. T.	0ʰ.6	Corr.	+ 0.4	G. M. T.	0ʰ.6
C. C.	− 5 38	d	4 47 06 S.	Corr.	−0′.6	Eq. t.	11 33.8 (*Add* to *mean* time.)	Corr.	+ 0ˢ.42
G. M. T	4 09 22								
Eq. t.	+ 11 33.8								

In setting watch, left an error making watch 18ˢ fast on L. A. T.
$L=90°-d-h$, or approx. $h=90°-(d+L)$.

G. A. T.	4 20 55.8	d	4° 47′	d	4 47 06	Corr. (Table 46) Approx. h=46° 52′	+ 9′ 02″
λ	4 48 23	L	38° 21′	Corr. +	10 52	I. C.	+ 1 50
L. A. T.	11 32 32.8	d+L	43° 08′	d+Corr.	4 57 58	Total Corr.	+ 10′ 52″

Approx. h=46° 52′

$L=L'\pm\Delta L$; $L'=90°-d-$obs. alt.$-at^2\pm$Corr. to alt. ∴ $L=90°-d-at^2\pm$Corr. to alt.$\pm\Delta L-$obs. alt.=K−obs. alt.
or $K=90°-d-at^2\pm$Corr. to alt. $\pm\Delta L$. Since ship is making northing, ΔL in this case is +.

If watch is 18ˢ fast, the observations should be taken at watch times:	11ʰ 45ᵐ 18ˢ	11ʰ 50ᵐ 18ˢ	11ʰ 55ᵐ 18ˢ	12ʰ 00ᵐ 18ˢ
But change in λ from these watch times to noon=$\frac{12'.2}{4}$, $\frac{12'.2}{6}$, $\frac{12'.2}{12}$=3′.0, 2′.0, and 1′.0	0 12	0 08	0 04	0 00
Hence the watch times to take observations are	11 45 30	11 50 26	11 55 22	12 00 18

For Lat. 38°.3 N., and Dec. 4°.88 S., we find from Table 26 that a=2.27, and from Table 27, $\frac{at^2}{\Delta L}$

$$\Delta L = \frac{4.76}{4}, \frac{4.76}{6}, \frac{4.76}{12} = 1'.2,\ 0'.8,\ 0'.4$$

	− 0° 8′ 30″ + 0 1 12	− 3′ 47″ + 0 48	− 0′ 57″ + 0 24	− 0′ 00″ + 0 00
d+Corr.	− 4° 57′ 58″	− 4° 57′ 58″	− 4° 57′ 58″	− 4° 57′ 58″
	5° 05′ 16″	5° 00′ 57″	4° 58′ 31″	4° 57′ 58″
∴ K	84 54 44	84 59 03	85 01 29	85 02 02
Observed Alts.	46 12 30	46 16 50	46 19 20	46 19 40
Noon Lat. by Obs.	38 42 14 N.	38 42 13	38 42 09	38 42 22

Mean	38° 42′ 14″.5 N.
Noon Lat. by D. R.	38 20 35 .0 N.
D. L.	21 39.5= 21′.66
Long. factor (Tab. 47)	0.65
	10830
	12996
Corr. in Long.	14′ 05″=14′.0790
Noon Long. by a. m. Obs.	72° 05′ 44″ W.
True longitude at noon.	71° 51′ 39″ W.

Lat. left.	36° 51′ 59″ N.	Long. left	75° 51′ 03″ W.
Lat. in	38 42 14 N.	Long. in	71 51 39 W.
D. L.	1 50 15=110′.2	D. Lo	3 59 24=239′.4

Course made good 59¾° Dist. 219 miles. Dep. 189.2.
Dist. made to point of Dep. 25

Total distance made	244
Total distance to destination	3,120
Distance to go	2,876

By Obs. Lat.	38 42.2 N.	Long.	71° 51.6 W.
By D. R. Lat.	38 20.6 N.	Long.	71 44.9 W.
D. L.	21.6 N.	D. Lo.	6.7 W.
			Dep.=5.3 W.

Current, 22.2 miles. Set=346°.
Drift=22.2 miles=1.2 knts. per hour.

From chart: Course for next 24 hrs.=72° (true).
Var. 10° W., Dev. 4° W. Compass course=86°

October 5, 1916.—P. M. Work.

Run to p. m. observation:

Course p. s. c.	Var.	Dev.	Comp. error.	True course.	Dist.	N.	E.	D. Lo.
86°	10° W.	4° W.	14° W.	72°	46.8	14′.5	44.5	57′.0 E.

Noon Lat. 38° 42.2 N.	Long. 71° 51.6 W.	
D. L. 14.5 N.	D. Lo. 57.0 E.	
4 p. m. D. R. Lat. 38 56.7 N.	Long. 70 54.6 W.	$\lambda = 4^h 43^m 38^s.4$

P. M. Sights of ☉

W. T.	$4^h 00^m 12^s$
C.-W.	4 40 56
C. T.	8 41 08.0
C. C. −	5 38.5
G. M. T.	8 35 29.5
Eq. t. +	11 36.8
G. A. T.	8 47 06.3
λ	4 43 38.4
L. A. T.	4 03 27.9

Obs. Alt. ☉ 18° 32′ 40″
Corr. + 8 57
h 18 41 37

=8.59 hrs. Oct. 5th

(Table 46) +7′ 07″
I. C. +1 50
Corr. +8 57

Dec. 8^h 4° 50′.4 S.
Corr. − 0.59
d 4 50 59 S.

H. D. −1′.0
G. M. T. $0^h.59$
Corr. −0′.59

Eq. t. 8^h, $11^m 36^s.4$
Corr. + .4
Eq. t. 11 36.8
(*Add* to *mean* time.)

H. D. $+0^s.70$
G. M. T. $0^h.59$
Corr. +0.413

t	$4^h 03^m 28^s$	log hav	9.40922		
L	38° 56′ 42″ N.	log cos	9.89084		
d	4 50 59 S.	log cos	9.99844		
θ		log hav	9.29850	nat hav	.19884
L∼d	43 47 41			nat hav	.13908
z	71 05 08			nat hav	.33792
Calculated *h*	18 54 52				
Observed *h*	18 41 37				
Alt. Diff.	13 15=13′.2 on reverse bearing of sun.				

From azimuth tables: With Lat. 38° N., Dec. 5° S. L. A. T. $4^h 00^m 00^s$ sun bears N. 113° 31′ W.
Corr. for Lat. 38°.94 =.94 × 19′ = +0° 18′
Corr. for Dec. 4.84 =.16 × 46 = −0 07
Corr. $4^h 03^m.5$ =.35 × 108 = −0 38
Total Corr. −0° 27′ − 0° 27′

True bearing N. 113° 04′ W.
Reverse bearing N. 66 56 E.

With distance, 13.2 (alt. diff.), on true course=N. 66° 56′ E.

True course.	Dist.	N.	E.	
66°.9	13.2	5′.2	12′.1	D. Lo.=15′.6 E.

Lat. by D. R.	38° 56′.7 N.	Long. 70° 54′.6 W.
D. L.	5.2 N.	D. Lo. 15.6 E.
4 p. m. Lat.	39 01.9 N.	Long. 70 39.0 W.
D. L.	14.5 N.	D. Lo. 57.4 E.
At 8 p. m. Lat.	39 16.4 N.	Long. 69 41.6 W.

Run to 8 p. m.:

True course.	Dist.	N.	E.	
72°	46.8	14′.5	44.5	D. Lo.=57′.4 E.

Course for night=86° p. s. c.

CHAPTER XVII.

MARINE SURVEYING.

408. Definitions.—Surveying is the art of making such field observations and measurements as are necessary to determine positions, areas, elevations, and movements on the surface of the earth, giving its characteristic features, such as, on land, the position of prominent objects, heights, and depressions, and on water, the depth, nature of bottom, position of shoals, and velocity of currents.

Topographic Surveying relates to the land, and *Hydrographic Surveying* to the water; and both are underlaid by *Trigonometrical Surveying* which, when it is carried on with high precision over such large areas as to contribute to form a basis for determining the size and shape of the earth, becomes a department of *Geodetic Surveying.*

It is not deemed appropriate to include in this work a complete treatise on marine surveying. The scope of this chapter will be to set forth such general information regarding the principles of surveying and the instruments therein employed as will give the navigator an intelligent understanding of the subject sufficient to enable him to comprehend the methods by which marine charts are made, and, if occasion should arise, to conduct a survey with such accuracy as the instruments ordinarily at hand on shipboard permit. For a more detailed discussion of marine surveying, the student is referred to the various publications which treat the subject exhaustively.

INSTRUMENTS EMPLOYED IN MARINE SURVEYING.

409. The Theodolite and Transit.—The *Theodolite* (fig. 62) is an instrument for the accurate measurement of horizontal and vertical angles. While these instruments vary in detail as to methods of construction, the essential principles are always identical.

A telescope carrying crosshairs in the common focus of the object glass and eyepiece is so mounted as to have motion about two axes at right angles to one another; graduated circles and verniers are provided by which angular motion in azimuth and (usually) in altitude may be measured; and the instrument is capable of such adjustment by levels that the planes of motion about the respective axes will correspond exactly with the horizontal and the vertical.

The telescope is carried in appropriate supports upon a horizontal plate which has, immovably attached to it, one or more verniers, and which revolves just over a graduated circle that is marked upon the periphery of a second horizontal plate, a means of measuring the motion of the upper plate relative to the lower one being thus provided. Thumb screws are fitted by which the upper plate may be clamped to the lower, and (excepting in some simpler forms of the instrument) others by which the lower plate may be made immovable in azimuth, or allowed free motion, at will; all clamping arrangements include slow-motion tangent screws for finer control.

A vertical graduated circle, or arc, with a vernier, clamps, and tangent screws, is fitted to most theodolites, for the measurement of the angular motion of the telescope in altitude.

The theodolite usually carries a magnetic needle, with a graduated circle and vernier for compass bearings. The instrument is mounted upon a tripod, and levels and leveling screws afford a means of bringing the instrument to a truly horizontal position.

The *Transit* used in surveying is a modified form of the theodolite, and is generally employed where less accuracy is required; it takes its name from the fact that the telescope may be turned completely about its horizontal axis, or *transited,* without removal from its supports.

410. The *line of collimation* of a telescope is an imaginary line passing through the optical center of the object glass in a direction at right angles to that of its axis of rotation. This is also called the *axis of collimation.* The *line of sight* is an imaginary line passing through the optical center of the object glass and the point of intersection of the cross hairs.

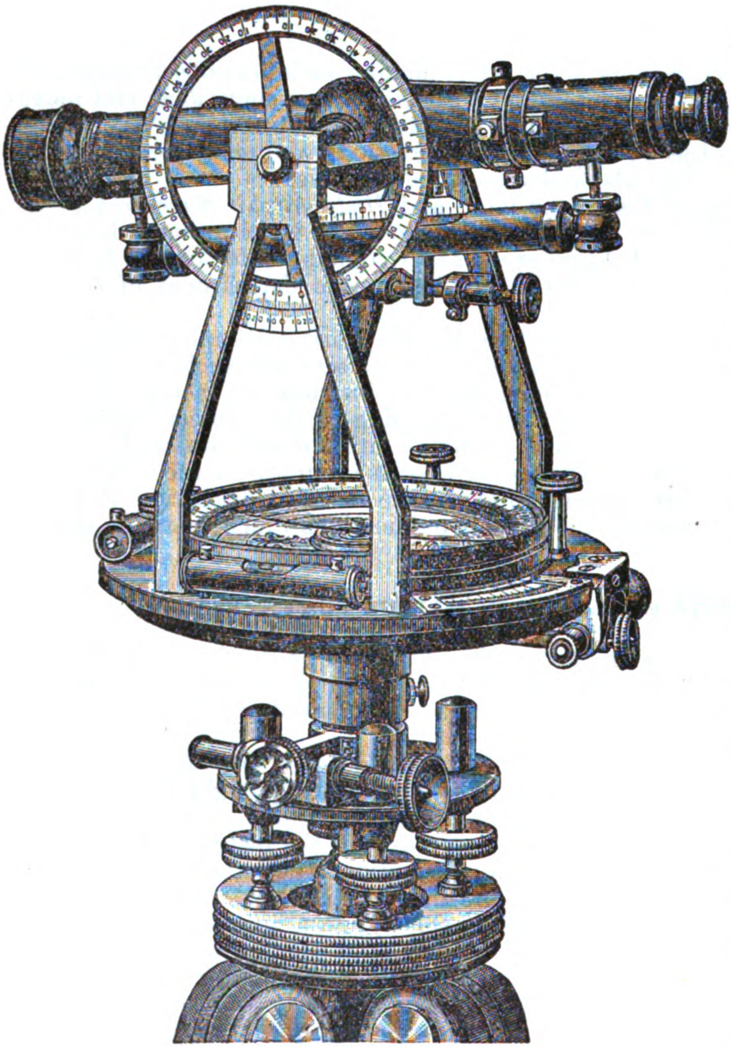

FIG. 62.

A theodolite or transit, before it can be used for the accurate measurement of angles, must be in adjustment in the following respects: (*a*) The vertical axes of revolution of the upper and lower horizontal plates must be coincident; (*b*) the axis must be vertical and the plates horizontal when the bubbles of the levels are in their central positions; (*c*) the vertical cross hair must be perpendicular to the horizontal axis of the telescope; (*d*) the line of collimation must coincide with the line of sight; (*e*) the horizontal axis of the telescope must be perpendicular to the vertical axis of the instrument; (*f*) the bubble of the telescope level must stand at the middle of its scale, and the vertical circle must read zero, when the line of collimation is horizontal.

The last-named condition may be disregarded if vertical angles are not to be measured.

411. The instrument being in adjustment, to observe angles it should be set up, leveled, and focused. This involves placing the tripod so that a plumb bob from the center of the instrument shall hang directly over the spot at which the measurement is to be made. The legs of the tripod should be firmly placed in such manner that the height shall be convenient for the observer and the instrument shall be nearly level. Then the horizontal plates are brought to a true level by means of the leveling screws and bubbles. The telescope should next be focused by moving the object glass and eyepiece in such manner that the object sighted and the cross hairs may be plainly seen and that the object will not appear to have motion relatively to the cross hairs as the eye is moved to the right or left of the eyepiece. This last condition insures the cross hairs being at the common focus of the eyepiece and objective.

To observe a horizontal angle with a theodolite or transit, clamp the upper plate to the lower at zero, leaving the lower plate unclamped; swing the telescope so that its vertical cross hair bisects one of the objects, and clamp the lower plate; unclamp the upper plate and bring the telescope to bisect the other object, and the reading of the vernier on the scale will give the required angle. (The final nice motion by which the cross hair is brought exactly upon a point is always given by the tangent screw.)

In taking a *round of angles*, this operation is repeated successively upon each object to be observed about the horizon, the upper plate always being swung, while the lower is kept where set upon the first object, or *origin*. The result will give the angular distance of each object from the origin, and, if the observations have been accurately made, upon finally sighting back to the origin, the reading should be zero.

To *repeat an angle*, having made the first measurement of it in the usual way, unclamp the lower circle and swing back the telescope until it again points to the first object, and clamp it; then unclamp the upper circle, swing to the second object, and clamp. The scale reading should now be double that of the first angle. Repeat as often as the importance of the angle requires, and the accepted value will be the final reading divided by the number of measurements. All angles of the main triangulation, and others of importance in the survey, are repeated.

Defects in adjustment of the instrument may be eliminated by taking one series of angles with the *telescope direct* and another with the *telescope reversed*. To reverse the telescope, revolve it about its horizontal axis through 180°, then swing it about its vertical axis through 180°—in other words, invert it.

Vertical angles are measured on the same principle as that described for horizontal ones.

The process of setting up the instrument at a station and observing the angles between the various objects that are visible is called *occupying* the station.

412. The Plane Table.—This is an instrument by which positions are plotted in the field directly upon a working sheet. It consists (fig. 63) of a drawing board mounted upon a tripod in such manner as to be capable of motion in azimuth, and with facilities for being brought to a perfect level; in connection with it is employed an alidade, consisting of a straightedge ruler, upon which is mounted a telescope with cross hairs whose line of sight is exactly parallel to the vertical plane through the edge of the rule. It is evident that if a sheet representing a chart be placed upon such a board and turned so that the true meridians, as portrayed thereon, lie in the direction of the earth's meridian at that place, then all lines of bearings on the chart will coincide with the corresponding lines on the earth's surface; from which it follows that if the alidade be so placed that its rule passes through the spot on the chart representing the position of the observer, while the telescope is directed to some visible object, the position of that object on the chart lies somewhere upon the line drawn along the edge of the rule. Upon this general principle depend the various applications of the plane table.

The drawing board is usually made of several pieces of well-seasoned wood, tongued and grooved together, with the grain running in different directions to prevent warping; about its edge are several metal clips for securing the paper in place. It is supported upon three strong brass arms, to which it is attached by screws, thus permitting its removal at will. The arms are attached to a horizontal plate which revolves upon a second horizontal plate lying immediately below it; a clamp and tangent screw are fitted, by which the upper plate, and with it the drawing board, may be secured to the lower plate, or may be given a fine motion in azimuth. Three equidistant lugs of brass, grooved on the under side, project down from the lower plate, resting on screws in the top of the tripod, by which the instrument is leveled; when adjusted in this respect it is firmly clamped in position, and, as the tripod is made unusually large, the adjustment is not easily deranged.

The alidade is a metal straightedge with a vertical column at its center, at the top of which are the supports which carry the telescope; a vertical arc and vernier are provided for measuring the motion of the telescope in altitude. The telescope is usually so fitted that it may be revolved in azimuth through an arc of exactly 180°, for the purpose of adjusting the line of collimation. On top of the rule near its center is the level—sometimes replaced by two levels at right angles—by means of which it may be seen when the table is in a true horizontal position.

A magnetic needle mounted in a rectangular metal box, whose outer straightedge is parallel to the zero line of a graduated scale over which the needle swings, is provided for drawing the north-and-south line on the chart; this is called a *declinatoire.*

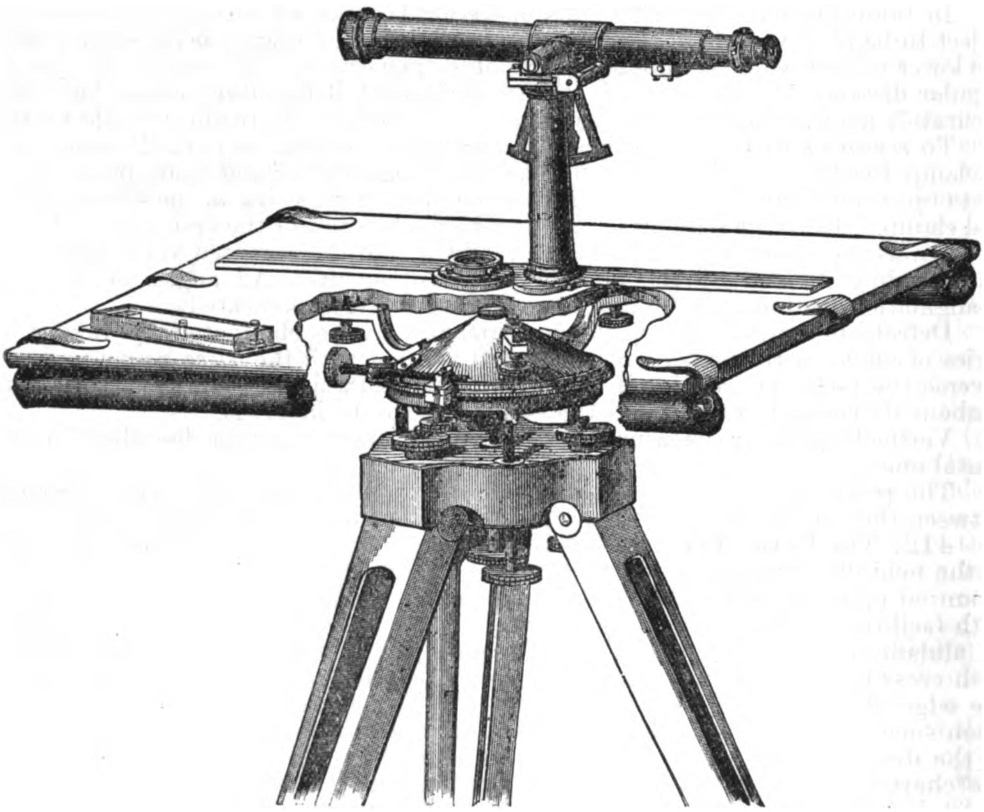

FIG. 63.

413. To be in correct adjustment, a plane table must comply with the following conditions:

(*a*) The fiducial edge of the rule must be perfectly straight. (*b*) The level must have the bubble in its central position when the table is truly horizontal. (*c*) The vertical cross hair must be perpendicular to the horizontal axis of the telescope. (*d*) The line of collimation must coincide with the line of sight. (*e*) The horizontal axis of the telescope must be parallel to the plane of the table. (*f*) The vertical circle should read zero when the line of collimation is horizontal.

414. The results derived from the use of the plane table, like all others dependent upon graphic methods, must be regarded as less accurate than those deduced by computation, and even less accurate than those derived from the careful plotting of theodolite angles. Hence it is that, in a careful marine survey, this instrument would be employed only for the topography and shore line.

For whatever purpose used, the plane table would not ordinarily be called into requisition until the survey had so far progressed that a chart could be furnished the observer showing certain stations whose positions were already established; with this chart, the first step would be to *occupy* one of the determined points. The table must be set up with the point on the chart directly over the center of the station; it must then be leveled and the telescope focused as described for the theodolite or transit; and finally it must be *oriented*—that is, so turned in azimuth that all lines of the chart are parallel to similar lines of the earth's surface. To orient, unclamp the table and swing it until the north-and-south line of the chart is approximately parallel to that of the earth, one means of doing which is afforded by the declinatoire; place the alidade so that the edge of the rule passes through the points on the chart representing the station occupied and some second station which is clearly in view; then, sighting through the telescope, perfect the adjustment of the table by swinging it until the second station is exactly bisected by the vertical cross hair, the final slow motion being obtained by clamping the table and working the tangent screw. If the adjustment has been correctly made, the rule may be laid along the line joining the station occupied and any other on the chart, and the telescope will point exactly to that other station.

Being properly oriented, if the alidade be so placed that the edge of the rule pass through the station occupied and the telescope point directly to some unknown object whose position is to be determined, then a line drawn along the rule will contain the point which represents the position of that object. If, now, the plane table be set up at a second station, oriented for its new position, and a line be similarly drawn from that station toward the one to be established, it will intersect the first line in the required point. This is the method of determining positions by *prosection*. Actually, the surveyor does not regard the point as well established until the intersection is checked by a line from a third station.

In practical work, of course, each station is not occupied separately for the determination of each point; the instrument is set up at a station, lines are drawn to all required points in view, and each line is appropriately marked; then a second station is occupied, and the operation is repeated, and so on, the various intersections being marked as the work proceeds.

A second method of establishing positions is that of *resection;* in this the first line is drawn from some known station, as in the preceding method, and the observer next proceeds to the place whose position is required and occupies it; the plane table is there oriented by means of the line already drawn, placing the edge of the rule along the line, sighting back toward the first station, and swinging the table until that station is in the line of sight of the telescope; then choose some other established station as nearly as possible at right angles to the direction of the first; place the edge of the rule upon the plotted position of this station and swing the alidade (the rule always being kept on the plotted point) until the object is bisected by the telescope cross hairs; draw this line, and its intersection with the first will give the required point, the accuracy of which can be checked from some other plotted station.

A third method of locating a point is by means of a single bearing from a known station, with the distance from the occupied station to the required one, the process of plotting being self-evident.

A fourth method is given by occupying an undetermined position from which three established stations are in view; the point occupied by the observer is then plotted by an application of the "three-point problem."

415. It may be seen that where the greatest accuracy is not essential the plane table may be employed for plotting all the points of a survey. In such a case it would only be necessary to begin with the two base stations, plotted on the sheet on any relative bearing whatsoever and at a distance apart equal to the length of the base line (reduced to scale), as measured by the most accurate means available. The work of plotting might even proceed before the base line had been measured, the two stations being laid off at any convenient distance apart; when later the base line was measured, the scale of the chart would be determined, being equal to the distance on the chart between base stations divided by the length of the base line.

416. A plane table could be improvised on shipboard which would greatly facilitate the operation of any surveying work that a vessel not equipped with instruments might be called upon to perform. A drawing board could be mounted upon a tripod (as, for example, the tripod supplied for compass work on shore) in such manner as to be capable of motion in azimuth; it could be brought nearly to the horizontal, if no better means offered, by moving the tripod legs, and this adjustment could be proved by any small spirit level; sight vanes could be erected upon an ordinary ruler to take the place of the alidade; in case there was difficulty in observing any object with such an alidade, because of its altitude or for other reasons, a horizontal angle might be observed with a sextant and plotted with a protractor. By this means work could be done which, even if it should lack complete accuracy, might be of great value.

417. The Telemeter and Stadia.—Any telescope fitted with a pair of horizontal cross hairs at the focus may be used as a *telemeter*, and when accompanied by a graduated staff, called a *stadia*, affords a means of measuring distance (up to certain limits) with a close degree of accuracy; the method consists in observing the number of divisions of the scale subtended by the hairs when the stadia is held perpendicular to the line of sight of the telescope, it being evident that the closer the distance the fewer divisions will appear between them. The facility with which distances can be measured by this method makes it most important that all telescopes of theodolites, transits, and plane tables be fitted as telemeters and that stadia rods be provided for all surveying work.

Speaking approximately, it may be said that the number of divisions intercepted between the cross hairs will vary directly as the distance of the stadia rod. This would be exactly true if we looked at the object through an empty tube, directly between the hairs. Since, however, the rays from the stadia are refracted by the object glass before they are intercepted by the wires, the statement, to be absolutely exact, must be slightly modified; but for practical surveying work it may be accepted as given.

418. There are two methods of installing the telemeter cross hairs—the first, in which they are immovably secured in the telescope and always remain at the same distance apart, and the second, in which the distance of the cross hairs is made variable, being under the control of the observer. The former is generally regarded as the preferable method, and when it is employed it is evident that the subtended height of the stadia bears a constant ratio to the distance of the staff from the telescope. It proves most convenient in practice to space the hairs so that this constant ratio is some even multiple of 10, for facility in converting scale readings into distance; it is also advantageous to mark the stadia in the unit of the chart scale and decimals thereof; for example, if the ratio of stadia height to distance were 100, and the stadia were marked in meters and decimals, a reading of 2.07 would at once be converted into a distance of 207 meters. Any units and any ratio may, however, be employed, and for any given setting of cross hairs it is very easy to graduate a stadia, by experiment, for any desired units; for example, if it is required to mark the stadia in feet, set up and level the telescope, measure off a distance of exactly 100 feet from it, hold up an unmarked staff and mark upon it the points intersected by the cross hairs; the interval between these marks will represent 100 feet of the scale; divide this length into 100 parts, each of which will represent a distance of one foot, and mark the whole staff on the same scale; then if the stadia be held up at any distance, the cross hairs will intercept a number of divisions corresponding to the number of feet of distance.

When the cross hairs are movable the ratio becomes variable, but the principle of measuring remains the same—namely, the distance of the staff from the telescope is equal to the existing ratio multiplied by the distance intercepted on the scale.

419. The stadia is made of a light, narrow piece of wood and is usually hinged for convenience in transporting. Ordinarily the background of the scale is painted white, while the main divisions are marked in red, with minor divisions in black, and geometrical figures are employed to facilitate the reading of fractional parts of the scale. Devices are furnished by which the man holding the stadia may know when it is vertical—an essential condition for accuracy of measurements.

420. The use of the telemeter and stadia for measuring distances is limited to the distance at which the scale divisions can be accurately read through the telescope. For fairly close work and with the class of telescope usually supplied with surveying instruments, 400 meters represents about the greatest distance at which it can be employed. With this limitation, the character of the survey determines the nature of its employment. In a careful survey its greatest use would be in connection with the theodolite or plane table in putting in shore lines, contour lines, and topography generally. In a survey where only approximate results are sought it might afford the best means for the measurement of the base.

421. If the telemeter be applied to a theodolite, transit, or plane table which is fitted with a graduated vertical arc or circle, it is possible to measure the distance to the stadia not only in a horizontal but also in a vertical direction. In this case the vertical angle must be observed as well as the stadia reading. Tables are computed giving the solution of the triangles involved when the stadia rod is held vertical.

422. In making a survey with the ordinary resources of a ship, the principle of the telemeter and stadia may be profitably employed, using a sextant and improvised staff. In this case it is usual to have the stadia of some convenient fixed length—as, for example, 10 feet—and of slight width and thickness; this is held at right angles to the line of sight from the observer, who notes the angle subtended by the total length; tables are prepared by which the distance corresponding to each angle is given.

423. THE SEXTANT.—This instrument is of the greatest value in hydrographic surveying. It is fully described elsewhere in this work and its adjustment explained. (Chap. VIII.)

Sextants are manufactured of a form especially adapted to surveying work; they are smaller and lighter than those usually employed in astronomical observations, but have a longer limb, by which angles may be measured up to 135°; the vernier is marked for quick reading and has no finer graduation than half minutes; the telescope has a large field.

This instrument is principally employed in measuring the horizontal angles by means of which soundings are plotted. It may, however, be put to various uses when making an approximate survey, as has already been explained. It should be remembered, in measuring terrestrial angles with a sextant, that rigorous methods require a reduction to the horizontal if either of the objects has material altitude above the horizon.

424. THE LEVEL.—This is an instrument for the accurate measure of differences of elevation. It consists of a telescope, carried in a Y-shaped rest, which is mounted upon a tripod and leveled in a manner similar to a theodolite; but it differs from that instrument in that the telescope is not capable of motion about a horizontal axis and in having no graduated circles for measurements of altitude and azimuth. The principle of its use contemplates placing the line of collimation of the telescope in a truly horizontal plane and keeping it so fixed.

425. It is principally employed in marine surveying to determine heights and contour lines—the latter being lines of equal elevation above the sea level—and for locating bench marks for tidal observations. (Chap. XX.) In connection with it is used a graduated staff called a *leveling rod*, carrying a conspicuous mark, adjustable in height, called a *target*. To ascertain the difference of level between any two points, set up the level with the telescope horizontal at some place between them; let an assistant take the leveling rod to one of the points, and, while holding it on the ground in a truly vertical position, move the target, under the direction of the observer at the telescope, to a point where it is exactly bisected by the horizontal cross hair; the height of the target on the staff—that is, the height of the cross hair above the level of the first point—is then accurately read with a vernier; now, without moving the level, shift the rod to the second point and again adjust the target and read it. It is evident that a comparison of the reading at the first position with that at the second will give the difference of height at the two points. The difference that can be read from one location of the instrument is limited by the length of the rod; but by making a sufficient number of shifts any difference may be measured.

The work of the level may be performed equally well by a theodolite whose telescope is adjusted to the true horizontal.

426. HELIOTROPE AND HELIOGRAPH.—These are instruments sometimes employed in surveying, by means of which the sun's rays may be reflected in any given direction; the object of their use is to render conspicuous a station which is to be observed at a distance and which would not otherwise be distinguishable. The instruments vary widely in form of construction and, in the absence of those made for the purpose, substitutes may easily be devised.

427. Astronomical Transit Instruments.—Various instruments are employed for the astronomical determinations necessary in a marine survey. Among these are the *zenith telescope* and *portable transit*. While differing in detail they consist essentially of a telescope mounted upon a horizontal axis that is placed truly in the prime vertical, thus insuring the revolution of the line of collimation in the meridian; a vertical graduated circle and vernier are supplied, affording a measure of altitude; in the focus are a number of equidistant vertical cross hairs or lines; a small lamp is so placed that its rays illuminate the cross hairs and render possible observations at night. Latitude is obtained by observing the meridian altitude of stars; hour angle (and thence longitude) by observing the times of their meridian transit, which is taken from the mean of the times of passing all of the vertical cross hairs.

Excepting in surveys of a most accurate nature, the astronomical determination of position by the sextant and artificial horizon is regarded as satisfactory.

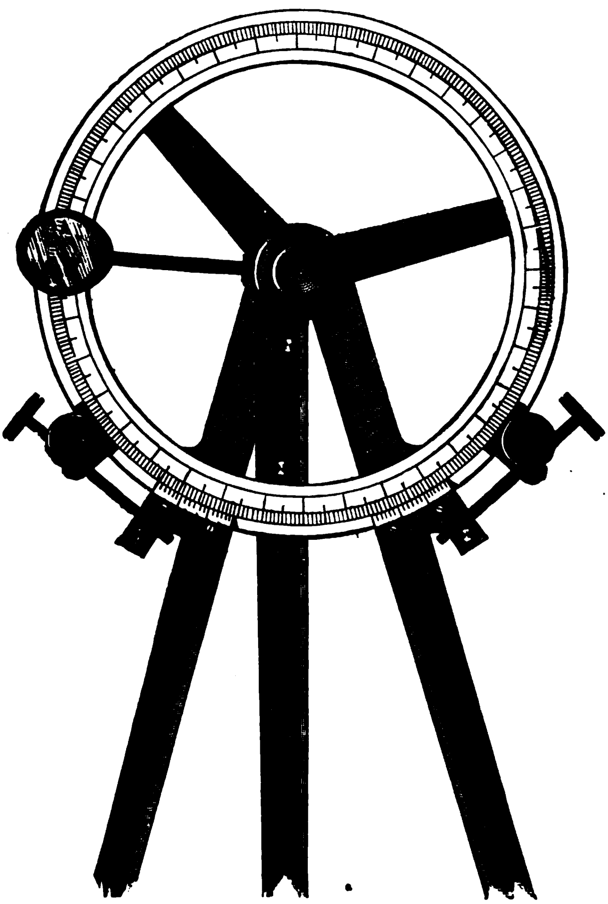

Fig. 64.

428. The Three-Armed Protractor, or Station Pointer.—This is an instrument whereby positions are plotted on the principle of the "three-point problem," of which an explanation is given in article 152, Chapter IV. It consists (fig. 64) of a graduated circle with three arms pivoted at the center; each arm has one edge that is a true rule, the direction of which always passes through the center of the circle. The middle arm is immovably fixed at the zero of the scale; the right and left arms each revolve about the center on their own sides, and are provided with verniers giving the angular distance from the middle arm. The protractor being set for the right and left angles, it is so moved that the three arms pass through the respective stations, when the center marks the position of the observer. Center pieces of various forms are provided, being cylindrical plugs made to fit into a socket at the pivot, and by employing one or the other of them the true center may be pricked with a needle, dotted with a pencil, or its position indicated by cross hairs. Adjustable arms are provided which can be fitted to the ends of the ordinary arms when working with distant signals.

The most valuable use of the three-armed protractor is in plotting the positions of soundings taken in boats, where sextant angles between signals are observed. It may occur, however, that certain shore stations will be located by its use.

429. As this instrument is not made with both right and left arms capable of being set to small angles down to 0°, the manufacturers make protractors with either small right or small left angles. Surveying parties should be equipped with both. In default of a three-armed protractor, a piece of *tracing paper* may be made to answer its purpose. To use the tracing paper, draw a line, making a dot on it to represent the center station, and with the center of an ordinary protractor on the dot, lay off the two observed angles right and left of the line; then, laying this on the plan, move it about till the three lines pass exactly through the three stations observed. The dot from which they were laid off will be on the position of the observer, and must be pricked lightly through or marked underneath in pencil.

430. THE BEAM COMPASS.—This instrument (fig. 65) is employed in chart drafting and performs the functions of compasses and dividers when the distance that must be spanned is beyond the limits of those instruments in their ordinary form. It consists of an angular bar of wood or metal upon which two instruments termed beam heads are fitted in such a manner that the bar may slide easily through them. A clamping screw attached to one side of the beam head will fix it in any part of its course along the beam. Upon each head a socket is constructed to carry a plain point, exchangeable for an ink or a pencil point. To secure accuracy the beam head placed at the end of the beam has a fine adjustment, which moves the point a short distance to correct any error in the first rough setting of the instrument. This adjustment generally consists of a milled-head screw, which passes through a nut fixed upon the end of the beam head, which it carries with its motion.

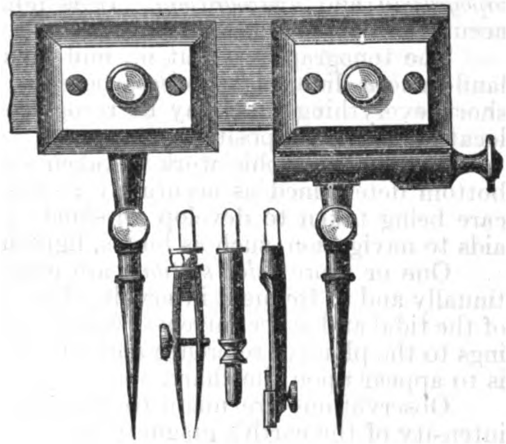

FIG. 65.

431. PROPORTIONAL DIVIDERS.—These are principally employed for reducing or enlarging drawings in any given proportion. They consist (fig. 66) of two narrow flat pieces of metal called *legs*, which turn upon a pivot whose position is movable in the direction of their length. The ends of both legs are shaped into points like those of ordinary dividers. When the pivot is fixed at the middle of the legs, any distance measured by the points at one end is just equal to that measured by those at the other; for any other location of the pivot, however, the distances thus measured will not be equal, but with a given setting of the pivot any distance measured by one end bears a fixed ratio to that measured by the other. The path of travel of the pivot is graduated so that the ratio may be given any desired value. Being adjusted in this respect, if a distance is taken off a chart with the legs at one end of the instrument, then those at the other end will show the same distance on the scale of a chart enlarged or reduced in the proportion represented by the ratio for which the pivot was set.

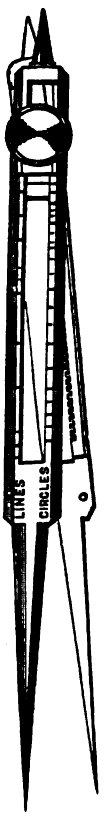

FIG. 66.

METHODS EMPLOYED IN A HYDROGRAPHIC SURVEY.

432. Before commencing a survey a general inspection of the field is made; a *base line* is located and its extremities marked by *signals;* certain other positions, known as *main triangulation points*, are selected and also marked with signals, being so chosen that, starting with the base and proceeding thence from one to another of these points, a series of well-conditioned triangles or quadrilaterals may cover the field of survey. The base line is measured with the greatest degree of accuracy which the resources of the survey render possible. Each extremity of the base line and each other main triangulation point is occupied by an observer with a theodolite, who measures the angles at each station between all the other stations which are in sight. An *astronomical determination* is made of the latitude and longitude of some point of the survey (frequently one of the extremities of the base) and of the true azimuth of some known line (frequently the base line). Data are now at hand for the location upon the chart of the base line and main triangulation points.

If the survey is one of considerable extent, it is expedient to measure a *check base* near the end of the triangulation. A comparison between the measured length of this base and its length as computed through the chain of triangles will show the degree of accuracy and afford a means of reconciling discrepancies. The position of a second observation spot may be determined for a similar purpose.

The *primary triangulation* gives a skeleton of the field, but the points thus determined are not usually close enough together to afford a basis for all the detail work that must be done. A second system of points is therefore selected and signals erected thereon, and the position of these points is determined by a series of angles from the main triangulation points and from one another. This is known as the *secondary triangulation*. The points thus located are used in the plotting of the *topography* and *hydrography*. It is not essential that their determination be as accurate as that of main triangulation points.

The topography is put in, and includes the delineation of the features of the land—shore line, lighthouses, beacons, contour lines, peaks, buildings, and, in short, everything that may be recognized by the navigator and utilized by him in locating the ship's position.

The hydrographic work is taken up and the depth of water and character of bottom determined as accurately as possible for the complete water area, especial care being taken to develop all shoals and dangers to navigation and to locate all aids to navigation, such as buoys, lightships, and beacons.

One or more *tidal stations* are established where observations are taken, continually and at frequent intervals, of the height of the tide and direction and velocity of the tidal and other currents, whence data are derived for the reduction of all soundings to the plane of reference and for the information about tides and currents which is to appear upon the chart.

Observations are made to determine the *magnetic* variation and dip, and the intensity of the earth's magnetic force.

433. The foregoing represent, in outline, the various steps that must be taken in the accumulation of the data necessary for the construction of a complete hydrographic chart. In the following paragraphs the details of the various operations will be more fully set forth.

The navigator who is called upon to conduct a marine survey without having available the time, instruments, and general facilities necessary for the most thorough performance of the work must exercise his discretion as to the modifications of method that he will make, and call upon his ingenuity to adapt his means to the particular work in hand.

434. The Base Line.—As the base line is the foundation for all distances on the chart, the correctness of the results of the survey will depend largely upon the degree of accuracy with which it is measured. The triangulation merely affords a measure of the various distances as compared with the distances between the two initial points from which it began; if that initial distance is 1,000 feet, we have certain values for the sides of the various triangles; if the same base line is 2,000 feet, the value of each side becomes twice as great as it was before; with the same triangulation, therefore, distances vary directly with the length of the base line; it may thus be seen that if an error exists in measurement which is only a small fraction of the total length, the error will become much more material as the more distant points of the survey are reached. In a base line 1,000 feet long, if a mistake of 10 feet be made all distances measured upon the chart will be in error 1 per cent, and a point plotted by triangulation 10 miles from the observation spot (the point at which plotting begins), would be out of its correct position one-tenth of a mile.

It is important that the base line should be as long as possible, consistent with the distribution and distances between the surrounding objects which must be depended upon as triangulation stations for its expansion. The position of the line must be such as to afford favorably conditioned triangles and quadrilaterals with adjoining main triangulation points, and its extremities must be visible from those points and from each other. The character of the ground and the facility for measuring will of course form an important consideration in the choice.

435. In measuring a base by tape, chain, or similar means, a number of successive fleets are made with the measure, whatever its nature, the distance traversed being appropriately marked after each fleet, while an observer, with a theodolite or transit, insures the measurement being made accurately along the line.

436. The most careful measurements are made with a steel tape 300 feet long, stretched along a series of supports at equal intervals along the base line, the points of support being made exactly horizontal by a level. A good form of support is a stake driven vertical with one side on the base line and a nail, for supporting the tape, driven horizontally into the stake at the established level. The stakes falling at the ends of tape lengths should be set slightly less than 300 feet apart, sawed off at the established level, and have strips of zinc tacked on their tops. The end of each fleet is marked by a scratch mark cut in the strip of zinc at an even hundredth of a foot-division on the tape, and the corresponding tape reading recorded. Tapes for base-line measurement are usually subdivided to hundredths of a foot for a distance of 10 feet from each end of the tape. The tape is stretched to a uniform tension by a spring balance. The temperature of the tape at each fleet should be observed, and the mean temperature, for the entire measurement of the base deduce. Tapes for base-line measurements are usually standardized lying flat, and at a temperature of 62° Fahrenheit. To reduce the measured length of the base line to the true length the following corrections to the measured length must be applied:

Temperature correction $C_t = +(\alpha T_m - T_o)\,L$,

where α = coefficient of expansion.
T_m = mean temperature at measurement.
T_o = standard temperature.
L = measured length.

Correction for sag $C_s = -\frac{L}{24}\left(\frac{wd}{P}\right)^2$.

where L = measured length.
w = weight per inch of tape.
d = distance between supports in inches.
P = tension in pounds.

By this method of measurement the horizontal distance between the ends of the base line may be readily found to within 1 part in 250,000, and by application of superior apparatus, of several measures, and greater care—hence, at an increased cost—the probable uncertainty may be reduced to 1 part in 500,000, but this degree of accuracy would not be necessary except in very extended systems of triangulation.

437. A second method of base measurement is with the surveyor's chain. This depends for accuracy upon the surface traversed being plane and level, a condition that is well fulfilled on a sandy beach, where the chain is nearly as accurate as the tape and much more rapid. A surveyor's chain is usually 100 feet long; the exact value of its length must be obtained by comparison with a standard, and a correction applied for expansion or contraction due to temperature. The ends of the fleets are marked by steel pins driven into the ground; the alignment is kept by the theodolite.

438. Where neither chain nor tape is available substitutes may be improvised from sounding wire taken from the deep-sea sounding machine, or failing this, from well-stretched cod line.

Measurements made by the telemeter and stadia afford a close approximation to the true result, and if these instruments are not at hand the sextant angle of a rod of fixed length can be employed. The masthead height of the vessel may be used in determining the length of base line on this principle, either by making the ship itself mark one of the extremities and observing the masthead angle from the other extremity, or by simultaneously observing the masthead angle from both ends of a shore base, and also the three horizontal angles of the triangle formed by the ship and the two base stations. The latter plan is far preferable where accuracy is sought, as, if the angles are all taken by different observers at the same instant (which can be marked by the hauling down of a flag), the error arising from the motion of the ship about her anchor is eliminated, and, moreover, the data furnished offers a double solution of the triangle and the mean may be taken as giving a closer result.

439. A crude method of estimating distance is by means of the velocity of sound, though this would never be used where close results are expected. Fire a gun at one end of the distance and at the other note by the most accurate means available the time between seeing the flash and hearing the report. Repeat several times in each direction. The mean number of seconds and tenths of a second multiplied by the velocity of sound per second at the temperature of observation (art. 314, Chap. XI) gives the approximate distance.

440. When for any reason the existing conditions do not permit of a direct measurement being made along the line between the two base stations, recourse must be had to a *broken base*, that is, one in which the length of the base is obtained by reduction from the measured length of two or more auxiliary lines. Necessity for resorting to a broken base arises frequently when the two stations are situated on a curving shore line and the straight line between them passes across water, or where wooded or unfavorable country intervenes, or where a stream must be crossed. The most common form of broken base is that in which the auxiliary lines run from each extremity of the base at an acute angle and intersect; in addition to measuring each of these lines the angle formed by their intersection or else the angles formed by them with the base line must be observed and the true length of the base deduced by solution of the triangle. The form that is most frequently used where only a short section of the base is incapable of measurement (as is the case where a deep stream flows across) is that of an auxiliary right triangle whose base is the required distance along the base line and altitude a distance measured along a line perpendicular thereto to some convenient point; by this measured distance and the angles which are observed, the triangle is solved and the length of the unmeasured section determined.

441. In a survey of considerable extent, where good means are at hand for the correct determination of latitude and longitude, a base line actually measured upon the earth may be dispensed with, and, instead of that, the positions of the two stations which are most widely separated may be determined astronomically and plotted; the triangulation is then plotted upon any assumed scale, and when it has been brought up to connect the two stations the true value of the scale is ascertained. This is called the method of an *astronomical base*.

442. SIGNALS.—All points in the survey whose positions are to be located from other stations, or from which other positions are to be located, must be marked by signals of such character as will render them distinguishable at the distance from which they are observed. The methods of constructing signals are of a wide variety.

A vessel regularly fitted out for surveying would carry scantlings, lumber, bolts, nuts, nails, whitewash, and sheeting for the erection of signals; however meager the equipment, the whitewash and sheeting (or some substitute for sheeting, preferably half of it white and half dark in color) should be provided, if possible, before beginning any surveying work. Regular tripod signals, which are quickly erected and are visible, under favorable circumstances, for many miles, are almost invariably employed to mark the main triangulation stations; among other advantages the tripod form permits the occupation with the theodolite of the exact center of the station, and avoids the necessity for the reduction which must otherwise be applied. Signals on secondary stations take an innumerable variety of forms, the requirement being only that they shall be seen throughout the area over which they are to be made use of; a whitewashed spot on a rock, a whitewashed trunk of a tree, a whitewashed cairn of stones, a sheeting flag, a piece of sheeting wrapped about a bush, or hung, with stones attached, over a cliff, or a whitewashed barrel or box filled with rocks or earth and surmounted by a flag, suggest some of the secondary signals that may be employed; sometimes objects are found that are sufficiently distinct in themselves to be used as signals without further marking, as a cupola or tower, a hut, a lone tree, or a bowlder; but it is seldom that an object is not rendered more conspicuous by the flutter of a flag above it, or by the dead-white ray reflected from a daub of whitewash.

For convenience, each signal is given some short name by which it is designated in the records.

For the sake of economy in both time and labor, steel towers, such as are used to support windmills, are being extensively employed by hydrographic parties for survey signals. They are very easily erected and dismounted, easily transported, offer little resistance to gales of wind, and are more permanent and satisfactory than signals of wood.

443. The Main Triangulation.—The points selected as stations for the main triangulation mark in outline the whole area to be surveyed; they are close enough together to afford an accurate means of plotting all intermediate stations of the secondary triangulation; and they are so placed with relation to one another that the triangles or quadrilaterals derived from them are well conditioned. The points are generally so chosen that small angles will be avoided. In order to fulfill the other conditions, it frequently becomes necessary to carry forward the triangulation by means of stations located on points a considerable distance inland, such as mountain peaks, which would not otherwise be regarded as properly within the limits of the survey.

Great care should be taken in observing all angles upon which the main triangulation is based; the best available instrument should be employed; angles taken with a theodolite or transit should be repeated, and observed with telescope direct and reversed, and the mean result taken; if the sextant is used, a number of separate observations of each angle should be taken and averaged for the most probable value. It must be remembered that while, in any other part of the work, an error in an angle affects only the results in its immediate vicinity, an error in the main triangulation goes forward through all the plotting that comes after it.

It occurs frequently that the purposes of the survey are sufficiently well fulfilled by a graphic plotting of the main triangulation, but where more rigorous methods prevail, the results are obtained by calculation. The sum of the angles of each triangle is taken, and if it does not exactly equal 180° the values are adjusted to make them comply with this condition. In cases where the triangulation stations form a series of quadrilaterals, the angles of each quadrilateral are adjusted so as to form a perfect geometrical figure. Allowance is made for the curvature of the earth where the area of triangles is sufficiently large to render it expedient to do so. The lengths of the various sides and the relative latitudes and longitudes of the several stations are then computed. Each station may then be plotted in its latitude and longitude on a polyconic projection, and a delineation of the triangulation system may thus be obtained free from the accumulated errors of a graphic plotting.

444. The Secondary Triangulation.—The points of the secondary triangulation are located, as far as possible, by angles from the main triangulation stations; these angles, having less dependent upon them, need not be repeated. A graphic plotting of these stations, without calculation, will suffice.

445. Astronomical Work.—This comprises the determination of the correct latitude and longitude of some point of the survey, and of the true direction of some other point from the observation spot, thus furnishing an origin from which all positions and all directions can be determined either graphically or by computation.

The methods of finding latitude, longitude, and the true bearing of a terrestrial object are fully set forth in previous chapters. The feature that distinguishes such work in surveying from that of determining the position of a ship at sea lies in the greater care that is taken to eliminate possible errors.

The results should therefore be based upon a very large number of observations, employing the best instruments that are available, and the various sights being so taken that probable errors are offset in reckoning the mean.

446. By taking a number of sights the observer arrives at the most probable result of which his instruments and his own faculties render him capable; but this result is liable to an error whose amount is indeterminate and which is equal to the algebraic sum of a number of small errors due, respectively, to his instruments (which must always lack perfection in some details), to an improper allowance for refraction under existing atmospheric conditions, and to his own personal error. Assuming, as we may, that the personal error is approximately constant, these three causes give rise to an error by which all altitudes appear too great or too small by a uniform but unknown amount. Let us assume, for an illustration, that this error has the effect of making all altitudes appear 30″ too great; if an observer attempted to work his latitude from the meridian altitude of a star bearing south, the result of this unknown error would give a latitude 30″ south of the true latitude;

if another star to the southward were observed, this mistake would be repeated; but if a star to the north were taken, the resulting latitude would be 30″ to the north. It is evident, therefore, that the true latitude will be the mean of the results of observation of the northern and the southern star, or the mean of the average of several northern stars and the average of several southern stars. A similar process of reasoning will show that errors in the determination of hour angle are offset by taking the mean of altitudes of objects respectively east and west of the meridian.

447. It must be remembered that the uniformity of the unknown error only exists where the altitude remains approximately the same, as instrumental and refraction errors may vary with the altitude; another condition of uniformity requires that the instrument and the observer remain the same, and that all observations be taken about the same time, in order that atmospheric conditions remain unchanged; to preserve uniformity, if the artificial horizon is used, the same end of the roof should always be the near one to the observer; in taking the sun, however, as the personal error may not be the same for approaching as for separating limbs, every series of observations should be made up of an equal number of sights taken under each condition.

448. With all of this in mind, we arrive at the general rule that astronomical determinations shall be based upon the mean of observations, under similar conditions, of bodies whose respective distances from the zenith are nearly equal, and which bear in opposite directions therefrom.

449. This condition eliminates the sun from availability for observations for latitude, though it properly admits the use of that body for longitude where equal altitudes or single a. m. and p. m. sights are taken. Opposite stars of approximately equal zenith distance should always be used for latitude, circum-meridian altitudes being observed during a few minutes before and after transit; excellent results are also obtained from stellar observations for longitude; but very low stars should be avoided, on account of the uncertainty of refraction, and likewise very high ones, as the reflection from the index mirror of the sextant may not be perfectly distinct when the ray strikes at an acute angle.

If there is telegraphic or radio communication, an endeavor should be made to obtain a time signal from a reliable source, instead of depending upon the chronometers.

450. Topography.—The plane table, with telemeter and stadia, affords the most expeditious means of plotting the topography, and should be employed when available. Points on shore may also be plotted by sextant angles, using the three-point problem, or by any other reliable method.

451. Hydrography.—The correct delineation of the hydrographic features being one of the most important objects of the survey, great care should be devoted to this part of the work. Soundings are run in one or more series of parallel lines, the direction and spacing of which depend upon the scope of the survey. It is usual for one series of lines to extend in a direction normal to the general trend of the shore line. In most cases a second series runs perpendicular to the first, and in surveys of important bodies of water still other series of lines cross the system diagonally. In developing rocks, shoals, or dangers the direction of the lines is so chosen as will best illustrate the features of the bottom. When lines cross, the agreement of the reduced soundings at their intersection affords a test of the accuracy of the work.

As the depth of water increases, if there is no reason to suspect dangers, the interval between lines may be increased.

Lines are run by the ship or boat in such manner as to follow as closely as possible the scheme of sounding that has been laid out. The position is located by angles at the beginning of each line, at each change of course, at frequent intervals along the line, and at the point where each line is finished. Soundings taken between *positions* are plotted by the time intervals or patent log distances.

452. There are a number of methods for determining positions while sounding, which may be described briefly as follows:

By two sextant angles.—Two observers with sextants measure simultaneously the angles between three objects of known position, and the position is located by the three-point problem. This is the method most commonly employed in boat work, and has the great advantage that the results may be plotted at once on the working sheet in the boat and the lines as run thus kept nearly in coincidence with those laid out in the scheme. A study of the three-point problem (art. 153, Chap. IV) will give the considerations that must govern in the selection of objects.

By two theodolite angles.—Two stations on shore are occupied by observers with theodolites, and at certain instants, indicated by a signal from the ship or boat, they observe the angular distance thereof from some known point. The intersection of the direction lines thus given is at the required position. This method is expeditious where the signals are small or not numerous. Its disadvantage is that the plotting can not be kept up as the work proceeds.

By one sextant and one theodolite angle.—An observer ashore occupies a station with a theodolite and cuts in the ship or boat, while one on board takes a sextant angle between two objects, of which one should preferably be the occupied station. It is plotted by laying off the direction line from the theodolite and finding with a three-armed protractor or piece of tracing paper at what point of that line the observed angle between the objects is subtended. Its advantages and disadvantages are the same as those of the preceding method.

In running lines of soundings offshore, where signals are lost sight of, the best method is to get an accurate departure, before dropping the land, by the best means that offers, keeping careful note of the dead reckoning, and on running in again, to get a position as soon as possible, note the drift and reconcile the plotting of intermediate soundings accordingly. Where circumstances require, the position may be located by astronomical observations as usually taken at sea.

453. A careful record of soundings must be kept, showing the time of each (so that proper tidal correction may be applied), the depth, the character of bottom, and such data as may be required to locate the position.

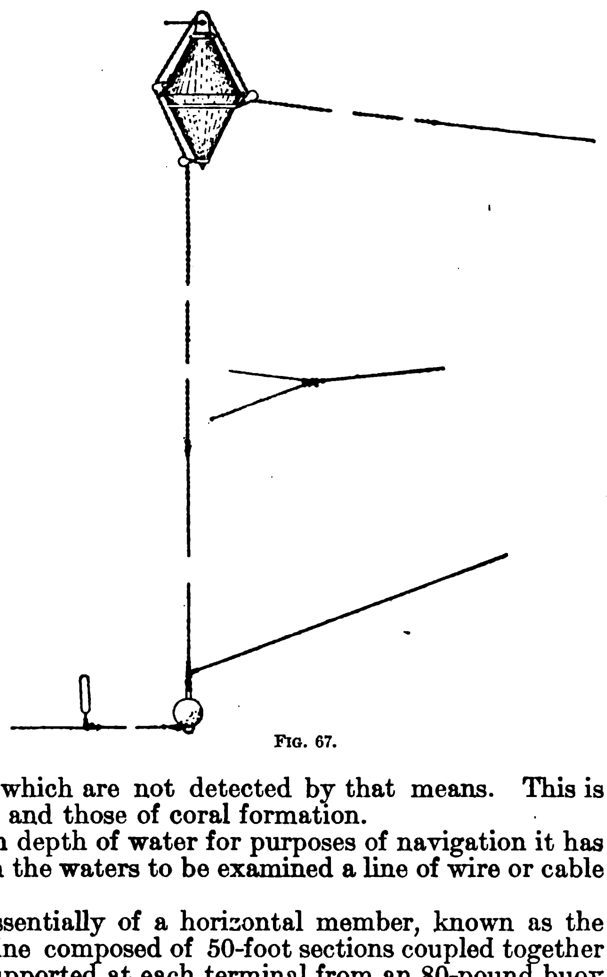

FIG. 67.

454. THE WIRE DRAG.—The use of the lead in hydrographic surveying does not absolutely establish a definite available depth, as pinnacle obstructions may exist which are not detected by that means. This is particularly true of rocky localities and those of coral formation.

In order to guarantee a certain depth of water for purposes of navigation it has become the practice to tow through the waters to be examined a line of wire or cable suspended at that depth.

The drag or sweep consists essentially of a horizontal member, known as the bottom wire, which is a long steel line composed of 50-foot sections coupled together with swivels and shackles. It is supported at each terminal from an 80-pound buoy by a chain stirrup line whose length may be adjusted from 20 to 50 feet. There are smaller buoys placed at intervals varying from 150 to 450 feet, according to local conditions, which support the wire by means of steel-cable stirrup lines, adjustable in length like the chain stirrup lines on the terminal buoys. At intermediate 50-foot connections, cedar toggles or floats, which have a little more buoyancy than is sufficient to support the wire between the stirrup lines, are attached by means of snap hooks. To prevent the bottom wire from sagging back as the drag is towed transversely to its own length by the bridles fastened at the terminals, a leaden weight of 165 pounds is suspended from each of the terminal stirrup lines, and a weight of 20 pounds from each of the intermediate stirrup lines. The length of the drag may be varied through a wide range to suit the conditions existing in the localities to be examined. Any multiple of 50 feet may be used, but it is in general found best to use, in each division between two towing launches, eight sections with stirrup-line suppports at their ends, each composed of from three to seven 50-foot units. The towing launches use tow lines about 200 feet in length bridled to the terminal stirrup lines with attachments at the top and bottom. During the towing, as long as the drag is free, the line of supporting buoys will trace out a parabolic curve on the surface of the water; but, if progress should be interrupted by a pinnacle of rock rising in its path above the depth to which the drag line is set, the parabolic curve of the line of buoys will immediately become broken into the form of a V, whose angle will correspond in position with the position of the pinnacle. The presence of any such obstruction is also registered by the spring balance usually attached to the towline at a convenient position near the towing vessel. If the shape of the obstruction is such as to allow the drag line to ride upward upon it, as may be with bowlders and shoals, an additional indication of its presence is afforded by the falling over of the supporting buoys when the suspended stirrup lines are relieved of strain by the grounding of the weights attached to them.

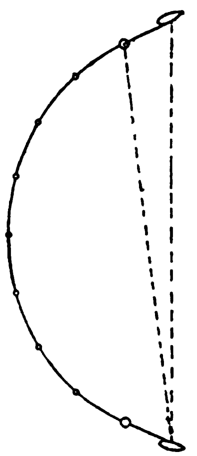

FIG. 68.

In such cases a tender should be in readiness to proceed to the indicated point for the purpose of taking position angles to locate the spot and also soundings to ascertain the characteristics of the obstruction. Such localities are plotted upon the chart upon which the paths of the drag line are being mapped, and later these areas are again swept with the drag line at a lesser depth; and this procedure is continued until the obstruction is cleared by the drag line, and thus the least depth is proved. The position of the drag is determined by observers with sextants on board the towing vessels who simultaneously measure, at frequent intervals, the values of two angles between two pairs of known objects whose positions are identified upon the plotting chart.

The average speed of towing is about 1½ knots per hour, and the average area explored per working day is 1½ square miles, although a much higher rate of progress is usually attained in open areas under favorable conditions.

455. TIDAL OBSERVATIONS.—These should begin as early as practicable and continue throughout the survey, it being most important that they shall, if possible, cover the period of a lunar month. In the chapter on tides (Chap. XX) the nature of the data to be obtained is explained.

456. MAGNETIC OBSERVATIONS.—The feature of the earth's magnetism with which the navigator is most concerned is the variation, which is set forth on the chart, and upon the determination of which will depend the correctness of all courses and bearings on shipboard. It is usually obtained by noting the compass direction from the observation spot of the object whose true bearing is known by calculation, and comparing the true and compass bearings; or it may be observed by mounting the ship's compass in a place on shore free from foreign magnetic influence, and finding the compass error as it is found on board. Observations for dip and intensity are also made when the proper instruments are at hand.

457. RUNNING SURVEY.—Where time and opportunity permit only a superficial examination of a coast line or water area, or where the interests of navigation require no more, recourse is had to a *running survey*, in which shore positions are determined and soundings are made while the ship steams along the coast, stopping only occasionally to fix her position, and in which the assistance of boat or shore parties may or may not be employed.

In this method the ship starts at one end of the field from a known position, fixed either by astronomical observations or by angles or bearings of terrestrial objects having a determined location. Careful compass bearings or sextant angles are taken from this position to all objects ashore which can be recognized, and a series of direction lines is thus obtained. The ship then steams along the coast, at a convenient distance therefrom, keeping accurate account of her run by compass courses and patent log. From time to time other series of bearings or angles are taken upon those objects ashore which are to be located, the direction lines plotted from the estimated position of the ship, and the various objects located by the intersections with their other direction lines. During all the time that the ship is under way, soundings are taken at regular intervals and plotted from the dead reckoning. As frequently as circumstances permit, the ship is stopped and her position located by the best available means, and the intervening dead reckoning reconciled for any current that may be found.

If a steam launch can be employed in connection with a running survey, it is usually sent to run a second line inshore of the ship. The boat's position is obtained by bearings of objects ashore which are located by the ship, or by bearings and masthead angles of the ship, or by such other means as offer. The duty of the boat is to take a series of soundings and to collect data for shore line and topography.

If circumstances allow the landing of a shore party, its most important duty is to mark the various objects on shore by some sort of signals which will render them unmistakable. Beyond this, it can perform such of the duties assigned to shore parties in a regular survey as opportunity permits.

CHAPTER XVIII.

WINDS.

458. *Wind* is air in approximately horizontal motion. Observations of the wind should include its true direction, and its force or velocity. The direction of the wind is designated by the point of the compass from which it proceeds. The force of the wind is at sea ordinarily expressed in terms of the Beaufort scale, each degree of this scale corresponding to a certain velocity in miles per hour, as explained in article 68, Chapter II.

459. The Cause of the Wind.—Winds are produced by differences of atmospheric pressure, which are themselves ultimately, and in the main, attributable to differences of temperature.

To understand how the air can be set in motion by these differences of pressure, it is necessary to have a clear conception of the nature of the air itself.

The atmosphere which completely envelops the earth may be considered as a fluid sea at the bottom of which we live, and which extends upward to a considerable height, probably 200 miles, constantly diminishing in density as the altitude increases.

The air, or material of which this atmosphere is composed, is a transparent gas, which, like all other gases, is perfectly elastic and highly compressible. Although extremely light, it has a perfectly definite weight, a cubic foot of air at ordinary pressure and temperature weighing 1.22 ounces, or about one seven hundred and seventieth part of the weight of an equal volume of water. In consequence of this weight it exerts a certain pressure upon the surface of the earth, amounting on the average to 15 pounds for each square inch. To accurately measure this pressure, which is constantly undergoing slight changes, we ordinarily employ a mercurial barometer (art. 48, Chap. II), an instrument in which the weight of a column of air of given cross section is balanced against that of a column of mercury having an equal cross section; and instead of saying that the pressure of the atmosphere is a certain number of pounds on each square inch, we say that it is a certain number of inches of mercury, meaning thereby that it is equivalent to the pressure of a column of mercury that many inches in height, and one square inch in cross section.

All gases, air included, are highly sensitive to the action of heat, expanding or increasing in volume as the temperature rises, contracting or diminishing in volume as the temperature falls. Suppose now that the atmosphere over any considerable region of the earth's surface is maintained at a higher temperature than that of its surroundings. The warmed air will expand, and its upper layers will flow off to the surrounding regions, cooling as they go. The atmospheric pressure at sea level throughout the heated areas will thus be diminished, while that over the circumjacent cooler areas will be correspondingly increased. As the result of this difference of pressure, there will be movement of the surface air away from the region of high pressure and toward the region of low, somewhat similar to the flow of water which takes place through the connecting bottom sluice as soon as we attempt to fill one compartment of a divided vessel to a slightly higher level than that found in the other.

A difference of atmospheric pressure at sea level is thus immediately followed by a movement of the surface air, or by winds; and these differences of pressure have their origin in differences of temperature. If the atmosphere were everywhere of uniform temperature it would lie at rest on the earth's surface—sluggish, torpid, and oppressive—and there would be no winds. This, however, is fortunately not the case. The temperature of the atmosphere is continually or periodically higher in one region than in another, and the chief variations in the distribution of temperature are systematically repeated year after year, giving rise to like systematic variations in the distribution of pressure.

460. The Normal Distribution of Pressure.—The winds, while thus due primarily to differences of temperature, stand in more direct relation to differences of pressure, and it is from this point of view that they are ordinarily studied.

In order to furnish a comprehensive view of this distribution of atmospheric pressure over the earth's surface, charts have been prepared showing the average reading of the barometer for any given period, whether a month, a season, or a year, and covering as far as possible the entire globe. These are known as isobaric charts, from the fact that all points at which the barometer has the same reading are joined by a continuous line or isobar.

The isobaric chart for the year (fig. 69) shows in each hemisphere a well-defined belt of high pressure (30.20 inches) completely encircling the globe, that in the northern hemisphere having its middle line about in latitude 35° North, that in the southern hemisphere about in latitude 30° South, these constituting the so-called meteorological tropics. From the summit or ridge of each of these belts the pressure falls off alike toward the equator and toward the pole, although much less rapidly in the former direction than in the latter. The equator itself is encircled by a belt of somewhat diminished pressure (29.90 inches), the middle line of which is ordinarily found in northern latitudes. In the northern hemisphere the diminution of pressure on the poleward slope is much less marked and much less regular than in the southern hemisphere, minima (29.70 inches) occurring in the North Atlantic Ocean near Iceland and in the North Pacific Ocean near the Aleutian Islands, beyond which the pressure increases. In the southern hemisphere no such minima are apparent, the pressure continuing to diminish uninterruptedly as higher and higher latitudes are attained. Along the sixtieth parallel of south latitude the average barometric reading is 29.30 inches.

461. Seasonal Variations of Pressure.—As might be expected from its close relation to the temperature, the whole system of pressure distribution exhibits a tendency to follow the sun's motion in declination, the barometric equator occupying in July a position slightly to the northward of its position in January. In either hemisphere, moreover, the pressure over the land during the winter season is decidedly above the annual average, during the summer season decidedly below it; the extreme variations occurring in the case of continental Asia, where the mean monthly pressure ranges from 30.50 inches during January to 29.50 inches during July. Over the northern ocean, on the other hand, conditions are reversed, the summer pressures being here somewhat the higher. Thus, in January the Icelandic and the Aleutian minima increase in depth to 29.50 inches, while in July these minima fill up and are well-nigh obliterated, a fact which has much to do with the strength and frequency of the winter gales in high northern latitudes and the absence of these gales during the summer. Over the southern ocean, in keeping with its slight contrast between winter and summer temperatures, similar variations of pressure do not exist.

462. The Prevailing Winds.—As a result of the distribution of pressure just described, there is in either hemisphere a continual motion of the surface air away from the meteorological tropic—on one side toward the equator, on the other side toward the pole, the first constituting in each case the trade winds, the second the prevailing winds of higher latitudes. Upon a stationary earth the direction of this motion would be immediately from the region of high toward the region of low barometer, the moving air steadily following the barometric slope or gradient, increasing in force to a gale where these gradients are steep, decreasing to a light breeze where they are gentle, sinking to a calm where they are absent. The earth, however, is in rapid rotation, and this rotation gives rise to a force which exercises a material influence over all horizontal motions upon its surface, whatever their direction, serving constantly to divert them to the *right* in the northern hemisphere, to the *left* in the southern. The air set in motion by the difference of pressure is thus constantly turned aside from its natural course down the barometric gradient or slope, and the direction of the wind at any point, instead of being identical with that of the gradient at that point, is deflected by a certain amount, crossing the latter at an angle which in practice varies between 45° and 90° (4 to 8 compass points), the wind in the latter case blowing parallel to the isobars. As a consequence of this deflection the northerly winds which one would naturally expect to find on the equatorial slope of the belt of high pressure in the northern hemisphere become

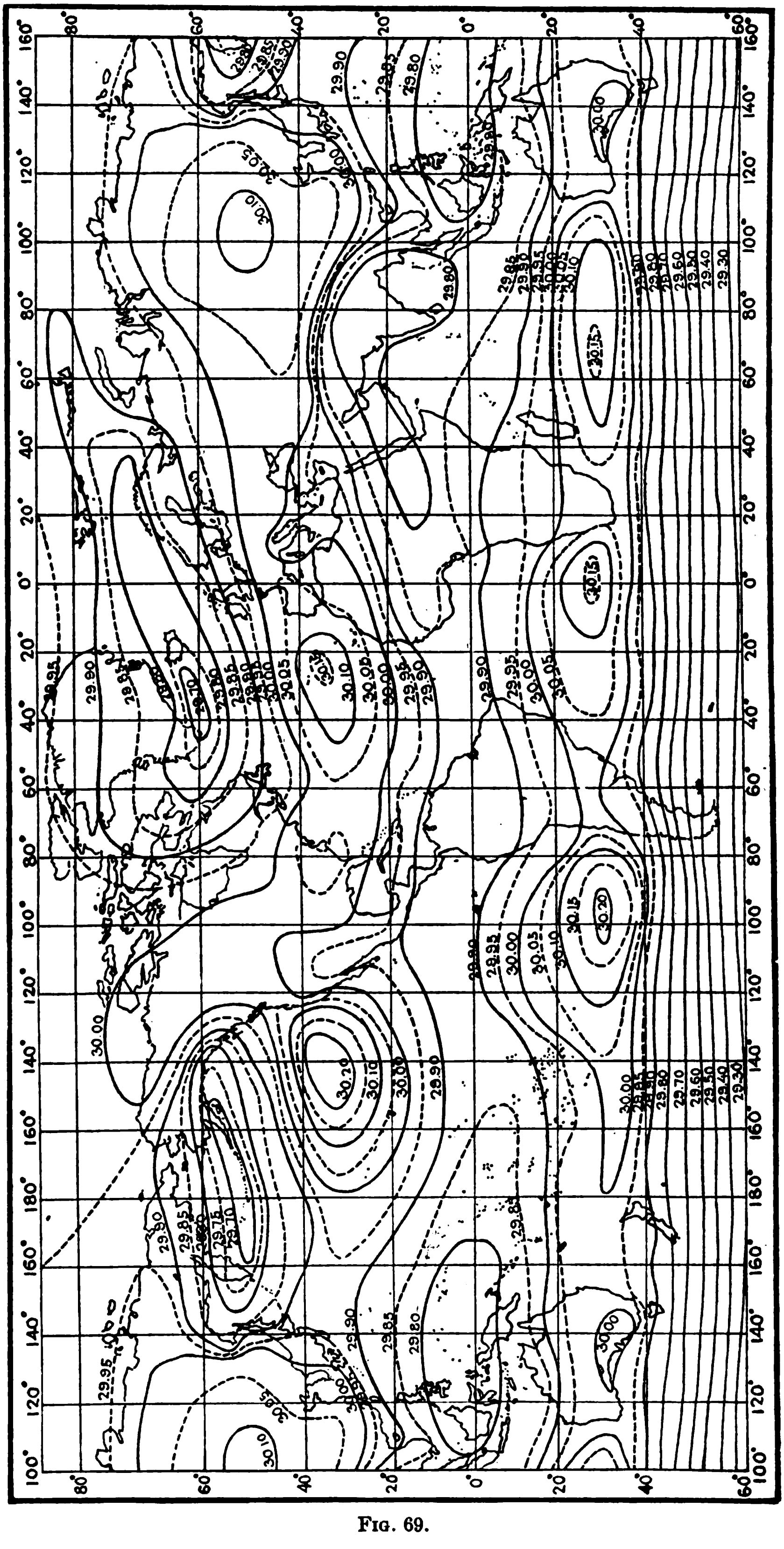

FIG. 69.

northeasterly—the NE. trade; the southerly winds of the polar slope become southwesterly—the prevailing westerly winds of northern latitudes. So, too, for the southern hemisphere, the southerly winds of the equatorial slope here becoming southeasterly—the SE. trades; the northerly winds of the polar slope northwesterly—the prevailing westerly winds of southern latitudes.

463. The relation here described as existing between the distribution of atmospheric pressure and the direction of the wind is of the greatest importance. It may be briefly stated as follows:

In the northern hemisphere stand with the face to the wind; in this position the region of high barometer lies on your left hand and somewhat in front of you; the region of low barometer on your right hand and somewhat behind you.

In the southern hemisphere stand with the face to the wind; in this position the region of high barometer lies on your right hand and somewhat in front of you; the region of low barometer on your left hand and somewhat behind you.

This relation holds absolutely, not only in the case of the general distribution of pressure and circulation of the atmosphere, but also in the case of the special conditions of high and low pressure which usually accompany severe gales.

464. The Trade Winds.—The *Trade Winds* blow from the tropical belts of high pressure toward the equatorial belt of low pressure—in the northern hemisphere from the northeast, in the southern hemisphere from the southeast. Over the eastern half of each of the great oceans they extend considerably farther from the line and their original direction inclines more toward the pole than in midocean, where the latter is almost easterly. They are ordinarily looked upon as the most constant of winds, but while they may blow for days or even for weeks with slight variation in direction or strength, their uniformity should not be exaggerated. There are times when the trade winds weaken or shift. There are regions where their steady course is deformed, notably among the island groups of the South Pacific, where the trades during January and February are practically nonexistent. They attain their highest development in the South Atlantic and in the South Indian Ocean, and are everywhere fresher during the winter than during the summer season. They are rarely disturbed by cyclonic storms, the occurrence of the latter within the limits of the trade-wind region being furthermore confined in point of time to the late summer and autumn months of the respective hemispheres, and in scene of action to the western portion of the several oceans. The South Atlantic Ocean alone, however, enjoys complete immunity from tropical cyclonic storms.

465. The Doldrums.—The equatorial girdle of low pressure occupies a position between the high-pressure belt of the northern and the similar belt of the southern hemisphere. Throughout the extent of this barometric trough the pressure, save for the slight diurnal oscillation, is practically uniform, and decided barometric gradients do not exist. Here, accordingly, the winds sink to stagnation, or rise at most only to the strength of fitful breezes, coming first from one point of the compass, then from another, with cloudy, rainy sky and frequent thunderstorms. The region throughout which these conditions prevail consists of a wedge-shaped area, the base of the wedge resting in the case of the Atlantic Ocean on the coast of Africa, and in the case of the Pacific Ocean on the coast of America, the axis extending westward. The position and extent of the belt vary somewhat with the season. Throughout February and March it is found immediately north of the equator and is of inappreciable width, vessels following the usual sailing routes frequently passing from trade to trade without interruption in both the Atlantic and the Pacific Oceans. In July and August it has migrated to the northward, the axis extending east and west along the parallel of 7° north, and the belt itself covering several degrees of latitude, even at its narrowest point. At this season of the year, also, the southeast trades blow with diminished freshness across the equator and well into the northern hemisphere, being here diverted, however, by the effect of the earth's rotation, into southerly and southwesterly winds, the so-called southwest monsoon of the African and Central American coasts.

466. The Horse Latitudes.—On the outer margin of the trades, corresponding vaguely with the summit of the tropical ridge of high pressure in either hemisphere, is a second region throughout which the barometric gradients are faint and undecided,

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and the prevailing winds correspondingly light and variable, the so-called *horse latitudes*, or calms of Cancer and of Capricorn. Unlike the doldrums, however, the weather is here clear and fresh, and the periods of stagnation are intermittent rather than continuous, showing none of the persistency which is so characteristic of the equatorial region. The explanation of this difference will become obvious as soon as we come to study the nature of the daily barometric changes of pressure in the respective regions, these in the one case being marked by the uniformity of the torrid zone, in the other sharing to a limited extent in the wide and rapid variations of the temperate.

467. The Prevailing Westerly Winds.—On the exterior or polar side of the tropical maxima the pressure again diminishes, the barometric gradients being now directed toward the pole; and the currents of air set in motion along these gradients, diverted to the right and left of their natural course by the earth's rotation, appear in the northern hemisphere as southwesterly winds, in the southern hemisphere as northwesterly—the prevailing westerly winds of the temperate zone.

Only in the southern hemisphere do these winds exhibit anything approaching the persistency of the trades, their course in the northern hemisphere being subject to frequent local interruption by periods of winds from the eastern semicircle. Thus the tabulated results show that throughout the portion of the North Atlantic included between the parallels 40°–50° North, and the meridians 10°–50° West, the winds from the western semicircle (South—NNW.) comprise about 74 per cent of the whole number of observations, the relative frequency being somewhat higher in winter, somewhat lower in summer. The average force, on the other hand, decreases from force 6 to force 4 Beaufort scale, with the change of season. Over the sea in the southern hemisphere such variations are not apparent; here the westerlies blow through the entire year with a steadiness little less than that of the trades themselves, and with a force which, though fitful, is very much greater, their boisterous nature giving the name of the "Roaring Forties" to the latitudes in which they are most frequently observed.

The explanation of this striking difference in the extra-tropical winds of the two halves of the globe is found in the distribution of atmospheric pressure, and in the variations which this latter undergoes in different parts of the world. In the landless southern hemisphere the atmospheric pressure after crossing the parallel of 30° South diminishes almost uniformly toward the pole, and is rarely disturbed by those large and irregular fluctuations which form so important a factor in the daily weather of the northern hemisphere. Here, accordingly, a system of polar gradients exists quite comparable in stability with the equatorial gradients which give rise to the trades; and the poleward movement of the air in obedience to these gradients, constantly diverted to the left by the effect of the earth's rotation, constitutes the steady westerly winds of the south temperate zone.

468. The Monsoon Winds.—The air over the land is warmer in summer and colder in winter than that over the adjacent oceans. During the former season the continents thus become the seat of areas of relatively low pressure; during the latter of relatively high. Pressure gradients, directed outward during the winter, inward during the summer, are thus established between the land and the sea, which exercise the greatest influence over the winds prevailing in the region adjacent to the coast. Thus, off the Atlantic seaboard of the United States southwesterly winds are most frequent in summer, northwesterly winds in winter; while on the Pacific coast the reverse is true, the wind here changing from northwest to southwest with the advance of the colder season.

The most striking illustration of winds of this class is presented by the *monsoons* (*Mausum*, season) of the China Sea and of the Indian Ocean. In January abnormally low temperatures and high pressure obtain over the Asiatic plateau, high temperatures and low pressure over Australia and the nearby portion of the Indian Ocean. As a result of the baric gradients thus established, the southern and eastern coast of the vast Asiatic continent and the seas adjacent thereto are swept by an outflowing current of air, which, diverted to the right of the gradient by the earth's rotation, appears as a northeast wind, covering the China Sea and the northern Indian Ocean. Upon entering the southern hemisphere, however, the same force which hitherto deflected the moving air to the right of the gradient now serves to deflect it to the left; and here, accordingly, we have the monsoon appearing as a northwest wind, covering the Indian Ocean as far south as 10°, the Arafura Sea, and the northern coast of Australia.

In July these conditions are precisely reversed. Asia is now the seat of high temperature and correspondingly low pressure, Australia of low temperature and high pressure, although the departure from the annual average is by no means so pronounced in the case of the latter as in that of the former. The baric gradients thus lead across the equator and are addressed toward the interior of the greater continent, giving rise to a system of winds whose direction is southeast in the southern hemisphere, southwest in the northern.

The northeast (winter) monsoon blows in the China Sea from October to April, the southwest (summer) monsoon from May to September. The former is marked by all the steadiness of the trades, often attaining the force of a moderate gale; the latter appears as a light breeze, unsteady in direction, and often sinking to a calm. Its prevalence is frequently interrupted by tropical cyclonic storms, locally known as *typhoons*, although the occurrence of these latter may extend well into the season of the winter monsoon.

469. Land and Sea Breezes.—Corresponding with the seasonal contrast of temperature and pressure over land and water, there is likewise a diurnal contrast which exercises a similar though more local effect. In summer particularly, the land over its whole area is warmer than the sea by day, colder than the sea by night, the variations of pressure thus established, although insignificant, sufficing to evoke a system of littoral breezes directed landward during the daytime, seaward during the night, which, in general, do not penetrate to a distance greater than 30 miles on and off shore, and extend but a few hundred feet into the depths of the atmosphere.

The sea breeze begins in the morning hours—from 9 to 11 o'clock—as the land warms. In the late afternoon it dies away. In the evening the land breeze springs up, and blows gently out to sea until morning. In the tropics this process is repeated day after day with great regularity. In our own latitudes, the land and sea breezes are often masked by winds of cyclonic origin.

470. A single important effect of the seasonal variation of temperature and pressure over the land remains to be described. If there were no land areas to break the even water surface of the globe, the trades and westerlies of the terrestrial circulation would be developed in the fullest simplicity, with linear divisions along latitude circles between the several members—a condition nearly approached in the land-barren southern hemisphere during the entire year, and in the northern hemisphere during the winter season. In the summer season, however, the tropical belt of high pressure is broken where it crosses the warm land, and the air shouldered off from the continents accumulates over the adjacent oceans, particularly in the northern or land hemisphere. This tends to create over each of the oceans a circular or elliptical area of high pressure, from the center of which the baric gradients radiate in all directions, giving rise to an outflowing system of winds, which by the effect of the earth's rotation is converted into an outflowing spiral eddy or *anticyclonic whirl*. The sharp lines of demarcation which would otherwise exist between the several members of the general circulation are thus obliterated, the southwesterly winds of the middle northern latitudes becoming successively northwesterly, northerly, and northeasterly, as we approach the equator and round the area of high pressure by the east; the northeast trade becoming successively southeasterly, southerly, and southwesterly, as we recede from the equator and round this area by the west; similarly for the other hemisphere.

CHAPTER XIX.

CYCLONIC STORMS.

471. VARIATIONS OF THE ATMOSPHERIC PRESSURE.—The distribution of the atmospheric pressure previously described (Chap. XVIII) and the attendant circulation of the winds are those which become evident after the effects of many disturbing causes have been eliminated by the process of averaging, or embracing in the summation observations covering an extended period of time. The distribution of pressure and the system of winds which actually exist at a given instant will in general agree with these in its main features, but may differ from them materially in detail.

Confining our attention for the time being to the subject of atmospheric pressure, it may be said that this, at any given point on the earth's surface, is in a constant state of change, the mercurial barometer rarely becoming stationary, and then only for a few hours in succession. The variations which the pressure undergoes may be divided into two classes, viz, periodic, or those which are continuously in operation, repeating themselves within fixed intervals of time, long or short; and nonperiodic or accidental, which occur irregularly, and are of varying duration and extent.

472. PERIODIC VARIATIONS.—Of the former class of changes the most important are the seasonal, which have been already to some extent described, and the diurnal. The latter consists of the daily occurrence of two barometric maxima, or points of highest pressure, with two intervening minima. Under ordinary circumstances with the atmosphere free from disturbances, the barometer each day attains its first minimum about 4 a. m. As the day advances the pressure increases, and a maximum, or point of greatest pressure, is reached about 10 a. m. From this time the pressure diminishes, and a second minimum is reached about 4 p. m., after which the mercury again rises, reaching its second maximum about 10 p. m. The range of this diurnal oscillation is greatest at the equator, where it amounts to ten hundredths (0.10) of an inch. It diminishes with increased latitude, and near the poles it seems to vanish entirely. In middle latitudes it is much more apparent in summer than in winter.

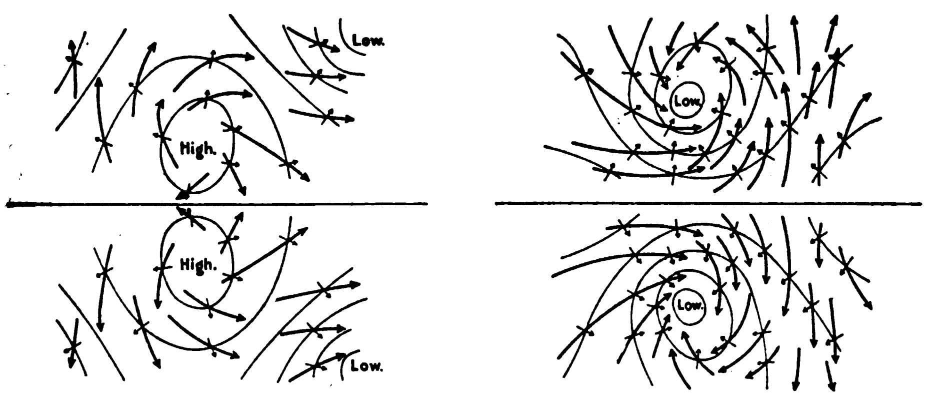
473. NONPERIODIC VARIATIONS.—The equatorial slope of the tropical belt of high pressure which encircles the globe in either hemisphere is characterized by the marked uniformity of its meteorological conditions, the temperature, wind, and weather changes proper to any given season repeating themselves as day succeeds day with almost monotonous regularity. Here the diurnal oscillation of the barometer constitutes the main variation to which the atmospheric pressure is subjected. On the polar slope of these belts conditions the reverse of these obtain, the elements which go to make up the daily weather here passing from phase to phase without regularity, with the result that no two days are precisely alike; and as regards atmospheric pressure, it may be said that in marked contrast with the uniformity of the torrid zone, the barometer in the temperate zone is constantly subjected to nonperiodic or accidental fluctuations of such extent that the periodic diurnal variation is scarcely apparent, the mercurial barometer at a given station frequently rising or falling several tenths of an inch in twenty-four hours.

474. PROGRESSIVE AREAS OF HIGH AND LOW PRESSURE.—The explanation of this rapid change of conditions is found in the approach and passage of extensive areas of alternately high and low pressure, which affect alike, although to a different degree, all the barometers coming within their scope. The general direction of motion of these areas is that of the prevailing winds; eastward, therefore, in the latitudes which are under consideration.

Taken in conjunction, these areas of high and low pressure exercise a controlling influence over the weather changes of the temperate zones. As the low area draws near, the sky becomes overclouded, the prevailing westerly wind falls away, and is succeeded by a wind from some easterly direction, faint at first, but increasing as the pressure continues to diminish; the lowest pressure having been reached, the wind again goes to the westward, the barometer starts to rise, and the weather clears; all marking the eastward recession of the low area and the approach of the subsequent high.

The first stage in the development of the low is a slight diminution of the atmospheric pressure, amounting in general to not more than one or two hundredths of an inch, throughout an area covering a more or less extensive portion of the earth's surface, either land or water, but far more frequently over the former than over the latter. Shortly after the advent of this initiatory fall the decrease of pressure throughout some small region within the larger area assumes a more decided character, the mercury here standing at a lower level than elsewhere and reading successively higher as we go outward, the region thus becoming, as it were, the center of the whole barometric depression. A system of barometric gradients is by this means established, all directed radially inward, and in obedience to these gradients there is a movement of the surface air toward the center or point of lowest barometer. The air once in motion, however, the effect of the earth's rotation is brought into play precisely as in the case of the larger movements of the atmosphere, with the result that the several currents, instead of following the natural course along these gradients, are deflected from them, in the northern hemisphere to the right hand, in the southern hemisphere to the left, the extent of the deflection being from 4 to 8 compass points.

Anticyclonic. NORTHERN HEMISPHERE. *Cyclonic.*



Anticyclonic. SOUTHERN HEMISPHERE. *Cyclonic.*

FIG. 70.

The light arrows show the direction of the gradients; the heavy arrows the direction of the winds.

475. CYCLONES AND CYCLONIC CIRCULATIONS.—A central area of low barometer will thus be surrounded by a system of winds which constantly draw in toward the center but at the same time circulate about it, the whole forming an inflowing spiral; the direction of this circulation being in the southern hemisphere with the motion of the hands of a watch, in the northern hemisphere opposed to this motion. Where the barometric gradients are steep, these winds are apt to be strong; where they are gentle, the winds are apt to be weak; where they are absent, as is the case at the center or bottom of the depression, calms are apt to prevail.

Around the center of the area of high pressure a similar system of wind will be found, but blowing in a contrary direction. Here the barometric gradients are directed radially outward, with the result that in place of the inflowing, we have an outflowing spiral, the circulatory motion being right handed or with the hands of a watch in the northern hemisphere, left handed or against the hands of a watch in the southern.

All these features are shown in the accompanying diagrams (fig. 70), which exhibit the general character of cyclonic (around the low) and anticyclonic (around the high) circulations in the northern and the southern hemisphere, respectively.

The closed curves represent the isobars, or lines along which the barometric pressure is the same; the short arrows show the direction of the gradients, which are everywhere at right angles to the isobars; the long arrows give the direction of the winds, deflected by the earth's rotation to the right of the gradients in the northern hemisphere, to the left in the southern.

476. Features of Cyclonic and Anticyclonic Regions.—Certain features of the two areas may here be contrasted. In the anticyclonic, the successive isobars are as a rule far apart, showing weak gradients and consequently light winds; the areas themselves are of relatively great extent, and their rate of progression is slow. During the summer they originate as extensions into higher latitudes of the margins of the tropical belts of high pressure; during the winter, as offshoots of the strong anticyclone which covers the land throughout that season. Their approach and presence is accompanied by polar or westerly winds, temperature below the seasonal average, fair weather, and clear skies. In the cyclonic area the successive isobars are crowded together, showing steep gradients and strong winds; they may appear either as trough-like extensions into the temperate zone of the polar belt of low pressure, in which case the easterly winds proper to their polar side are nonexistent, or (in lower latitudes) as independent areas, sometimes, indeed, as detached portions of the equatorial low-pressure belt, which move eastward and poleward across the temperate zone, and are ultimately merged into the great cyclonic area surrounding the pole. The progress of these independent areas is invariably attended by the strong and steadily shifting winds, foul weather, and other features which make up the ordinary storm at sea. In the trough-like depressions of higher latitudes these features may or may not be observed, their presence depending upon the depths of the barometric trough and the steepness of its slopes. In these, moreover, the cyclonic circulation is never completely developed, the storm winds having rather the character of right line gales, blowing from an equatorial or easterly direction until the axis of the trough is at hand, and as this passes shifting by the west at one bound to a polar direction.

477. Cyclonic Storms.—Strong winds are the result of steep barometric gradients. These may occur with cyclonic or with anticyclonic areas, the latter being exemplified in the case of the northers in the Gulf of Mexico and the northwesterly winter gales along the Atlantic coast of the United States, which are almost invariably accompanied by barometers above the average. They are, however, so much more frequent in the case of areas of low pressure and consequent cyclonic circulations, with their attendant foul-weather characteristics, that the latter are generally known as cyclonic storms, i. e., storms in which the wind circulation is cyclonic.

Cyclonic storms may with convenience be divided into two classes: viz, tropical, or those which originate near but not on the equator; and extra-tropical, or those which first appear in higher latitudes.

478. Tropical Cyclonic Storms.—The occurrence of tropical cyclonic storms is confined to the summer and autumn months of the respective hemispheres, and to the western part of the several oceans, the North Atlantic, the North Pacific, the South Pacific, and the Indian Ocean. They are unknown in the South Atlantic Ocean. Although these cyclonic storms are all of the same essential characteristics, they have generally been called hurricanes when occurring in the West Indies and the region between Samoa and Australia, typhoons when occurring in the region of the Philippines, and cyclones when occurring in the Indian Ocean and its dependent seas.

The limits of the regions within which these tropical storms originate are defined by parallels of latitude and meridians of longitude as follows:

	Latitude.	Longitude from Greenwich.
Hurricanes of the West Indies	12° to 28° N.	55° to 95° W.
Typhoons of the Philippine region	5 to 20 N.	150 to 115 E.
Cyclones of the Bay of Bengal	8 to 22 N.	100 to 80 E.
Cyclones of the Indian Ocean	4 to 30 S.	100 to 40 E.
Hurricanes of the Samoan region	10 to 30 S.	160 W. to 150 E.

The percentage of frequency of these storms in the different months of the year is set forth in the following table:

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Hurricanes of the West Indies	0	0	0	0	1	6	4	25	32	31	1	0
Typhoons of the Philippine region	2	0.4	1	2	5	9	16	16	19	14	11	5
Cyclones of the Bay of Bengal	0	0	0	0	6	12	19	15	20	14	10	4
Cyclones of the Indian Ocean	22	19	18	15	6	1	0.5	0	0	1.5	7	10
Hurricanes of the Samoan region	29	17.5	28	6	1	0	0	0	1.5	1	3	13

The yearly average number of those occurring in the West Indian region is 4, in the Philippine region 21, in the Bay of Bengal 9, in the Indian Ocean (south of the Equator) 9, and in the region between Samoa and Australia 4.

479. MOTION OF THE STORM CENTER.—In the case of tropical cyclonic storms there is always a tendency for the barometric depression, impelled by the general motion of the atmosphere in the trade-wind region, to follow a path which tends at once westward and away from the equator. This motion continues until the limits of the trades are reached, where the path ordinarily recurves; and the subsequent motion of the depression is eastward and toward the pole, the disturbance at the same time assuming the features of the extra-tropical cyclonic storm.

Rate of progress of the storm center.—Within the tropics in the northern hemisphere, the average velocity of the storm center along the path is 11 miles an hour; and in the latitude of the recurvature of the storm this average is maintained, although there are numerous instances of wide variations in the rate of progress here, and sometimes the center becomes stationary for a few days. In higher latitudes, the rate increases to an average of 16 miles an hour.

In the southern hemisphere, the average velocity of progress as far as determined is somewhat less than in the northern; and, in the Indian Ocean, many of the Mauritius cyclones have a very small movement of translation, and these are, in consequence, designated as stationary cyclones.

The general path of the tropical cyclonic storm in either hemisphere and the cyclonic circulation of the wind about the storm center are given in figures 73 and 74; that for the northern hemisphere applying to the hurricanes of the West Indies; that for the southern hemisphere to the hurricanes of the South Pacific Ocean.

480. INDICATIONS OF THE APPROACH OF TROPICAL CYCLONIC STORMS.—The premonitory signs of a tropical cyclonic storm comprise, besides those feelings of personal discomfort which are common within the sphere of atmospheric disturbance of cyclonic storms in all parts of the world, (1) an unsteady barometer, or even a cessation of the diurnal range, which is constant in settled weather; (2) a heavy swell not caused by the wind then blowing; (3) the appearance of the sky arising from the forms and movements of the clouds. It is upon the concomitance of these indications, rather than the recognition of any one of them, that reliance should be placed.

The appearance of the clouds and their value as storm warnings is described as follows by Faura in the Cyclones of the Far East, by José Algue, of the Manila Observatory:

The best means for determining the center [of a storm] and for following up its movements are the observations of cirri, little clouds of a very fine structure and clear opal color, which appear as elongated feathers. * * * Long before the least sign of bad weather is noticeable and in many cases when the barometer is still very high—being under the influence of a center of high pressure, which generally precedes a tempest—these small isolated clouds appear in the upper regions of the atmosphere. They seem to be piled up on the blue vault of heaven and drawn out in the direction of some point on the horizon toward which they converge. The first to present themselves are few in number but well defined and of the most delicate structure, appearing like filaments bound together but whose visibility is lost before they reach the point of radiation. We often had an opportunity to watch them at the observatory of Manila, when the center was still 600 miles distant. The best times for observing the cirri are sunrise and sunset. If the sun is in the east and very near the horizon, the first clouds which are tinged by the solar rays are the cirro-strati which precede the cyclone, and they are also the last to disappear at sunset, inasmuch as they overspread the horizon. Such times are the best for determining the radiant point of the cloud streaks and at the same time for ascertaining the direction in which the center lies. Later on the delicacy of form, which characterizes this class of clouds in its earlier stages, is lost, and the clouds appear in more confused and tangled forms, like streamers of feather work, with central nuclei, which still maintain this direction, so that the point of radiation can still be detected. In order to ascertain approximately the direction in which the center is advancing in its movement of translation, it is necessary

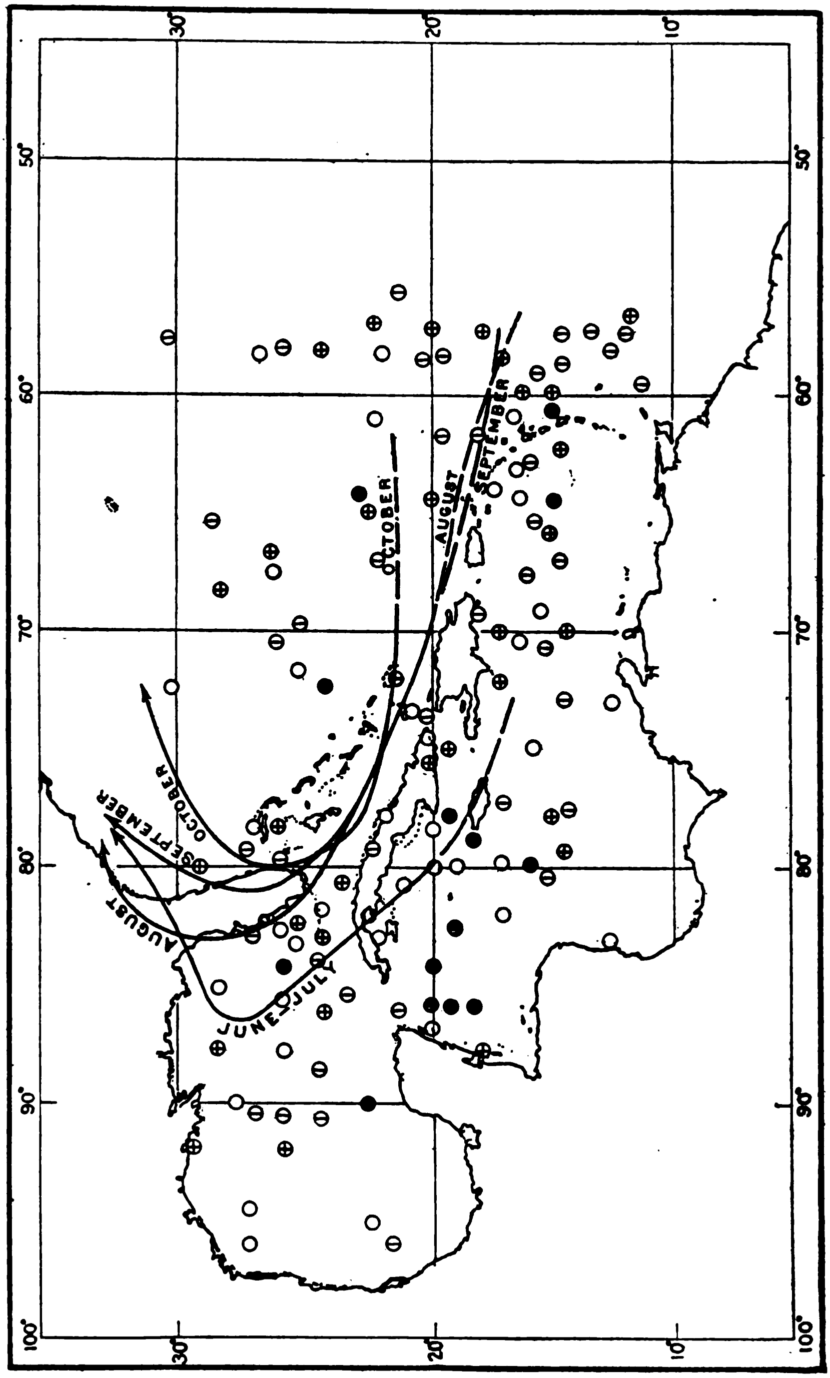


FIG. 71.—Average Paths of Hurricanes in the West Indies.

The small circles indicate the points of origin of 130 storms, which comprise all the instances resulting from the authentic accounts of a period of 35 years.

June and July storms — September storms
August storms — October storms

to determine the changes of the radiant point at equal intervals of time and to compare them with the movements of the barometer. If the point of convergence does not perceptibly change its position, but remains fixed and immovable for a long time, even for several consecutive days, it is almost certain that the tempest will break over the position of the observer. In this case the barometer begins to fall shortly after the first cirrus clouds have been observed and sometimes even before. At first it falls slowly, without

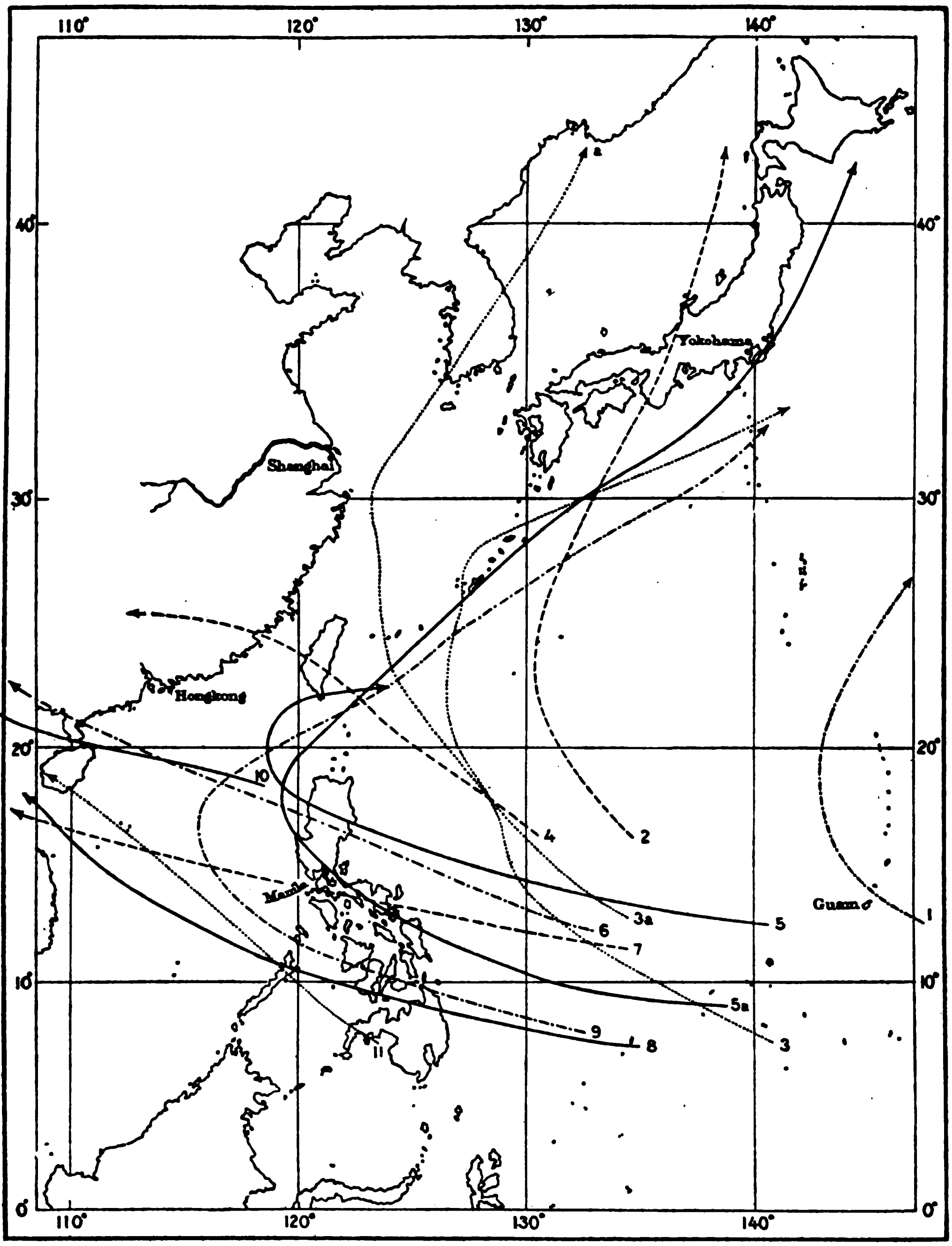


FIG. 72.—Mean Paths of Typhoons.

1. Typhoons in the Marianas.
2. Typhoons formed in the Pacific which, at some distance east of the meridian of Manila, have recurved toward Japan.
3 and 3a. Typhoons formed in the Pacific which, near the meridian of Manila, have recurved toward Japan.
4. Typhoons of Taiwan or Formosa.
5 and 5a. Typhoons of northern Luzon which have recurved in the island or near it in the China Sea.
6. Typhoons which have crossed Luzon northward of Manila and continued to the continent.
7. Typhoons which have crossed Luzon southward of Manila.
8. Typhoons of the Visayas and Mindanao.
9. Typhoons formed in the Pacific which have crossed south of Manila, recurved in the China Sea between latitudes 10 degrees and 20 degrees, and recrossed north of Manila.
10. Typhoons formed in the China Sea.
11. Typhoons formed in the Sulu Sea and the interisland waters.

completely losing the diurnal and nocturnal oscillatory movements, but changing somewhat the hours of maximum and minimum. The daily reading is observed to be each day less than that of the preceding day. That part of the horizon in the direction of the storm begins to be covered by a cirrus veil, which increases slowly until it forms an almost homogeneous covering of the sky. This veil is known by the name "cirro-pallium" of Poëy, and is that which causes the solar and lunar halos, which are never absent when a storm approaches. Beneath the veil a few isolated clouds, commonly called "cotton," appear. They are much more numerous and larger on the side lying toward the storm, where they soon appear as a compact mass. At such times the sunrises and sunsets are characterized by the high red tint which the clouds assume, resembling a great fire, especially in the direction of the cyclone. The wind remains fixed at one point, showing only a few variations, which are due principally to the squalls, which continually exert their force within the limits of the storm. The low or "cotton" clouds successively and from time to time cover the sky, throwing out occasional squalls of rain and wind; but, the squalls having passed, a lull ensues, the cirrus veil remaining, and likewise the hurricane bank of clouds, which seems fixed to the same spot in the direction of the storm. This state of the atmosphere continues until the bank of clouds invades the point of observation, in which case the squalls will be continuous and the wind will increase in violence each moment.

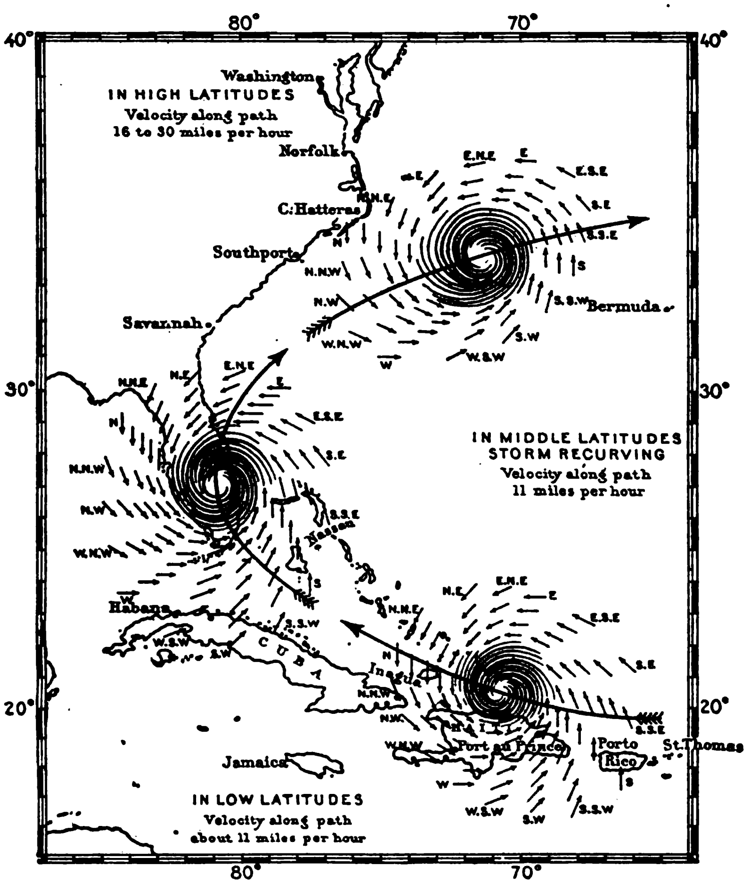


FIG. 73.

The condition of diminished pressure attending a cyclonic storm gives rise to high waves which are propagated in all directions from such a storm on the ocean. These waves outrun the storm as much as a thousand miles, and, by the direction from which they arrive, indicate the bearing of the storm's center.

Although thunderstorms can not be considered as premonitory signs, it rarely happens that showers and squalls are not experienced from 24 to 48 hours in advance of the storm; and the unsettled state of the barometer in the distant approaches, varying from 500 to 1,000 miles in advance of the center, gives place, at a distance of 300 to 400 miles, to a slow and steady fall of the mercurial column. At the same time the direction and velocity of the lower clouds show unmistakable evidence of the presence of a storm and the bearing of the center. When the storm center is still far distant, the phenomenon called the "bar of the cyclone" may frequently be seen. This is a dense mass of rain cloud formed about the center of the storm, giving the appearance of a huge bank of black clouds resting upon the horizon, which may retain its form unchanged for hours. It is usually most conspicuous about sunrise or sunset. When it is possible to observe this bar, the changes in its position at intervals of a few hours will enable the observer to determine the direction of movement of the storm.

481. CHARACTER OF TROPICAL CYCLONIC STORMS.—Within the tropics the storm area is small, the region covered by violent winds extending in general not more than 150 miles from the center. The barometric gradients are, however, exceedingly steep, instances having been recorded in which the difference of pressure

for this distance amounted to 2 inches. In the typhoons of the North Pacific Ocean gradients of one inch in 60 miles are not infrequent. The successive isobars are almost circular. As a consequence of this distribution of pressure the winds on the slopes of the depression are frequently of great violence, and in the matter of direction they are more symmetrically disposed about the center than is the case with the larger and less regularly shaped depressions of higher latitudes. In these low latitudes the average values of the deflection of the wind from the barometric gradient is in the neighborhood of six compass points—to the right in the northern hemisphere, to the left in the southern.

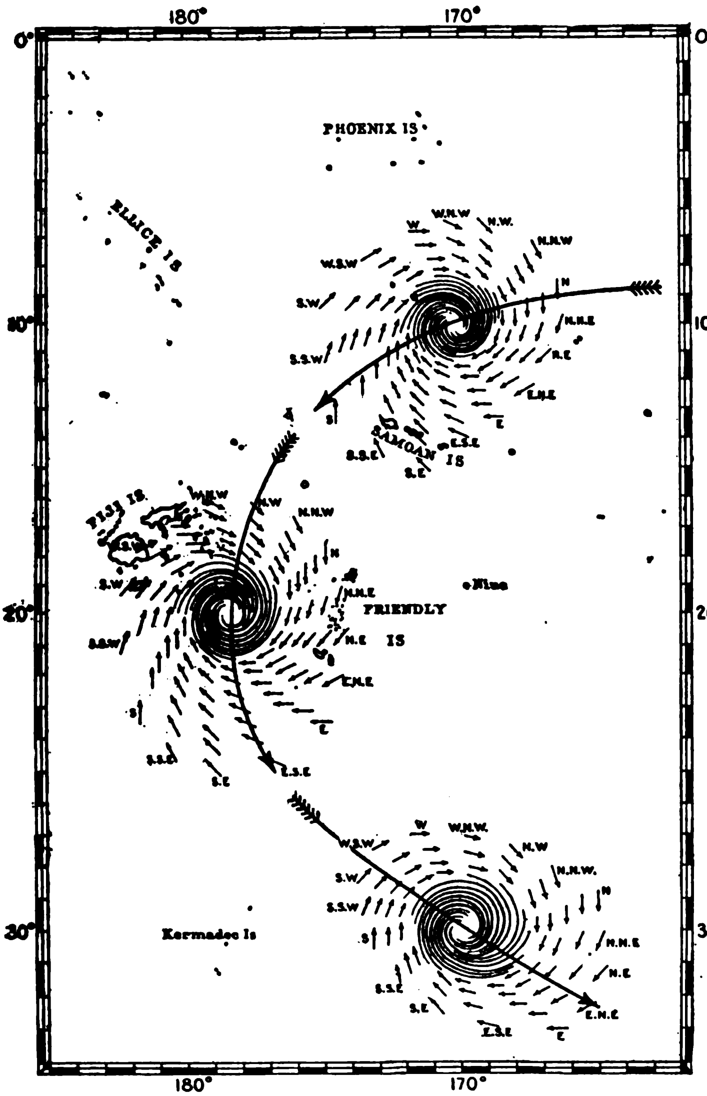


Fig. 74.

482. To Fix the Bearing of the Storm Center from the Vessel.—On this assumption, the following rules will enable an observer to fix the bearing of the storm center from his vessel:

In the northern hemisphere, stand with the face to the wind; the storm center will bear ten points to the observer's right.

In the southern hemisphere, stand with the face to the wind; the storm center will bear ten points to the observer's left.

On the basis of these rules the tables hereafter given (art. 487) show the bearing of the center corresponding to a wind of any direction.

483. To Fix the Distance of the Storm Center from the Vessel.—The following table, taken from Piddington's "Sailor's Horn Book," may prove of some assistance in estimating the distance of the storm center from the vessel:

Average fall of the barometer per hour.	*Distance from the storm center.*
From 0. 02 to 0. 06 in.	From 250 to 150 miles.
From 0. 06 to 0. 08 in.	From 150 to 100 miles.
From 0. 08 to 0. 12 in.	From 100 to 80 miles.
From 0. 12 to 0. 15 in.	From 80 to 50 miles.

The table assumes that the vessel is hove-to in front of the storm and that the latter is advancing directly toward it.

Inasmuch as cyclones are of varying area and of different intensities, the lines of equal barometric pressure (isobars) lie much closer together in some storms than in others, so that, in the circumstances of an observer on the ocean, the estimation of the distance of the center by the height of the mercurial column or of its rate of fall must be somewhat conjectural.

484. To Avoid the Center of the Storm.—In the immediate neighborhood of the center itself the winds attain full hurricane force, the sea is exceedingly turbulent, and there is danger of being taken aback. Every effort should therefore be made to avoid this region, either by running or by heaving-to; and if recourse is had to the latter maneuver, much depends upon the selection of the proper tack; this being in every case the tack which will cause the wind to draw aft with each successive shift.

A vessel hove-to in advance of a tropical cyclonic storm will experience a long heavy swell, a falling barometer with torrents of rain, and winds of steadily increasing force. The shifts of wind will depend upon the position of the vessel with respect to the path followed by the storm center. Immediately upon the path, the wind will hold steady in direction until the passage of the central calm, the "eye of the storm," after which the gale will renew itself, but from a direction opposite to that which it previously had. To the right of the path, or in the right-hand semicircle of the storm (the observer being supposed to face along the track), the wind, as the center advances and passes the vessel, will constantly shift to the right, the rate at which the successive shifts follow each other increasing with the proximity to the center; in this semicircle, then, in order that the wind shall draw aft with each shift, the vessel must be hove-to on the starboard tack; similarly, in the left-hand semicircle, the wind will constantly shift to the left, and here the vessel must be hove-to on the port tack.

These rules hold alike for both hemispheres and for cyclonic storms in all latitudes.

Figure 75 represents a cyclonic storm in the northern hemisphere after recurving. For simplicity the area of low barometer is made perfectly circular, and the center is assumed to be ten points to the right of the direction of the wind at all points within the disturbed area. Let us assume that the center is advancing about NNE., in the direction of the long arrow, shown in heavy full line. The ship *a* has the wind at ENE.; she is to the left of the track, or technically in the navigable semicircle. The ship *b* has the wind at ESE. and is in the dangerous semicircle. As the storm advances these ships, if lying to, *a* upon the port tack, *b* upon the starboard tack, as shown, take with regard to the storm center the successive positions a, a_1, etc., b, b_1, etc., the wind of ship *a* shifting to the left, of ship *b* to the right, or in both cases drawing aft, and thus diminishing the probability of either ship being taken aback, a danger to which a vessel lying to on the opposite tack (i. e., the starboard tack in the left-hand semicircle or the port tack in the right-hand semicircle) is constantly exposed, the wind in the latter case tending constantly to draw forward. The ship *b* is continually beaten by wind and sea toward the storm track. The ship *a* is drifted away from the track, and, should she be able to carry sail, would soon find better weather by running off to the westward.

It must not be forgotten that the shifts of wind will only occur in the above order when the vessel is stationary. When the course and speed are such as to maintain a constant relative bearing between the ship and storm center, there will be no shift of wind. Should the vessel be outrunning the storm, the wind will indeed shift in the opposite direction to that given, and a navigator in the right semicircle, for instance, and judging only by the shifts of wind without taking into account his own run, might imagine himself on the opposite side. In such a case the barometer must be the guide.

An examination of figure 75 shows how this is. A vessel hove to at the position marked *b*, and being passed by the storm center, will occupy successive positions in regard to the center from b to b_4, and will experience shifts of wind, as shown by the arrows, from East through South to SW. On the other hand, if the storm center be stationary or moving slowly and a vessel be overtaking it along the line from b_4 to b, the wind will back from SW. to East, and is likely to convey an entirely wrong impression as to the location and movement of the center.

485. Dangerous and Navigable Semicircles.—Prior to recurving, the winds in that semicircle of the storm which is more remote from the equator (the right-hand semicircle in the northern hemisphere, the left-hand semicircle in the southern) are liable to be more severe than those of the opposite semicircle. A vessel hove to in the semicircle adjacent to the equator has also the advantage of immunity from becoming involved in the actual center itself, inasmuch as there is a distinct tendency on the part of the latter to move away from the equator. For these reasons the more remote semicircle has been called the *dangerous,* the less remote the *navigable.*

486. Maneuvering.—A vessel suspecting the dangerous proximity of a tropical cyclonic storm should lie-to for a time on the starboard tack to locate the center by observing shifts of the wind and the behavior of the barometer. If the former holds

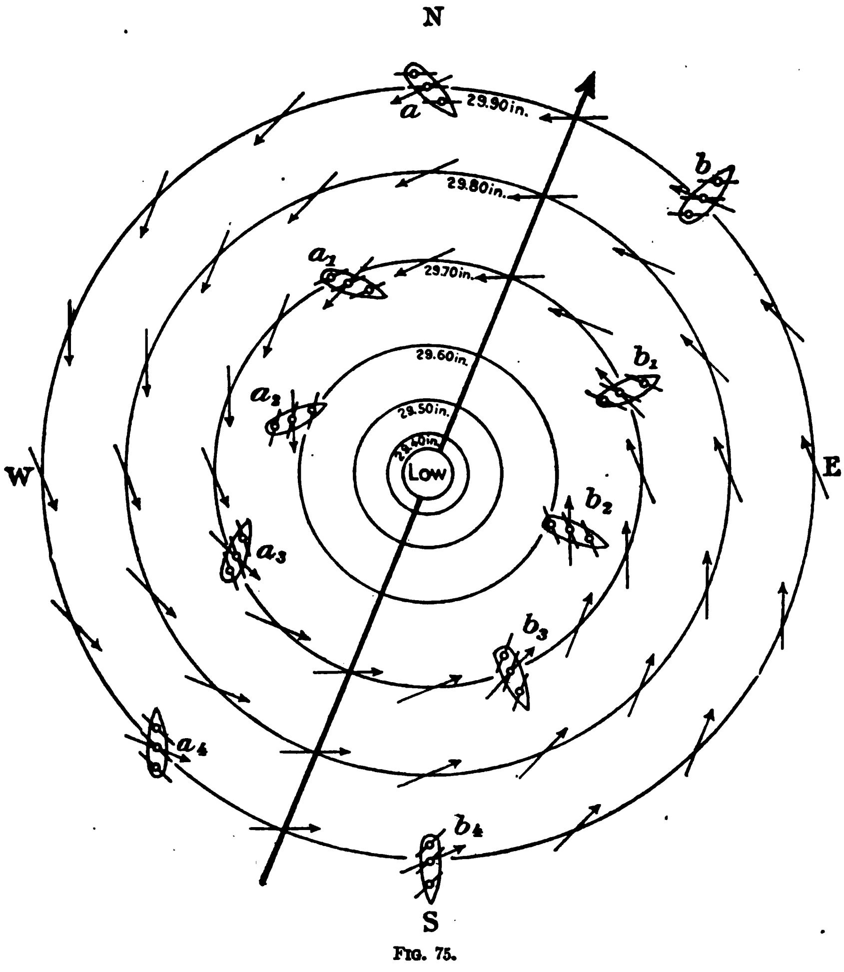


Fig. 75.

steady and increases in force, while the latter falls rapidly, say at a greater rate than 0.03 of an inch per hour, the vessel is probably on the track of the storm and in advance of the center. In this position the proper step (providing, of course, that sea room permits) is to run, keeping the wind, in the northern hemisphere, at all times well on the starboard quarter; in the southern hemisphere, well on the port; and thus constantly increasing the distance to the storm center. The same rule holds good if the observation places the vessel at but a scant distance within the forward quadrant of the dangerous semicircle. Here, too, the natural course will be to seek the navigable semicircle of the storm, even though such a course involves crossing the track in advance of the center, always exercising due caution to keep the wind from drawing too far aft.

The critical case is that of a vessel which finds herself in the forward quadrant of the dangerous semicircle and at a considerable distance from the track, for here the shifts of the wind are sluggish and the indications of the barometer are undecided, both causes conspiring to render the bearing of the center doubtful. If, upon heaving to, the barometer becomes stationary, the position should be maintained until indications of a rise are apparent, upon which the course may be resumed with safety and held as long as the rise continues. If, however, the barometer falls, a steamer should make a run to the NNE. or NE. (southern hemisphere, SSE. or SE.), keeping the wind and sea a little on the port (southern hemisphere, starboard) bow, and using such speed as will at least keep the barometer stationary. Such a step will in general be attended with the assurance that the present weather conditions will in any case grow no worse. For a sailing vessel, unable to stand closer to the wind than six points, the last maneuver will be impossible, and driven to leeward by wind, sea, and current, she may be compelled to cross the track immediately in advance of the center, or may even become involved in the center itself. In this extremity the path of the storm center during the past twenty-four hours should be laid down on a diagram as accurately as the observations permit, and the line prolonged for some distance beyond the present position of the center. Having assumed an average rate of progress for the center, its probable position on the line should be frequently and carefully plotted, and the handling of the vessel should be in accordance with the diagram.

487. Summary of Rules.—The following summary comprises the rules of maneuvering, so far as they may be made general:

NORTHERN HEMISPHERE.

In the Right or Dangerous Semicircle.—Steamers bring the wind on the starboard bow, and make as much way as possible; if obliged to heave to, do so head to sea. Sailing vessels haul by the wind on the starboard tack and carry sail as long as possible; if obliged to heave to, do so on the starboard tack.

In the Left or Navigable Semicircle.—Bring the wind on the starboard quarter, note the course, and hold it; if obliged to heave to, do so on the port tack, unless in a steamer which behaves better when hove to stern to the sea.

On the Storm Track in Front of the Center.—Bring the wind two points on the starboard quarter, and, holding this course, run for the Left Semicircle; if obliged to heave to, do so on the port tack, unless in a steamer which behaves better when hove to stern to the sea.

On the Storm Track in Rear of the Center.—Avoid the center by the best practicable route, having due regard to the tendency of cyclones to recurve to the northward and eastward.

SOUTHERN HEMISPHERE.

In the Left or Dangerous Semicircle.—Steamers bring the wind on the port bow, and make as much way as possible; if obliged to heave to, do so head to sea. Sailing vessels haul by the wind on the port tack, and carry sail as long as possible; if obliged to heave to, do so on the port tack.

In the Right or Navigable Semicircle.—Bring the wind on the port quarter, note the course, and hold it; if obliged to heave to, do so on the starboard tack, unless in a steamer which behaves better when hove to stern to the sea.

On the Storm Track in Front of the Center.—Bring the wind two points on the port quarter, and, holding this course, run for the right semicircle; if obliged to heave to, do so on the starboard tack, unless in a steamer which behaves better when hove to stern to the sea.

On the Storm Track in Rear of the Center.—Avoid the center by the best practicable route, having due regard to the tendency of cyclones to recurve to the southward and eastward.

The application of these rules for the various directions of the wind is shown in the following table:

Storm Table, Northern Hemisphere.

Direction of wind.	Direction of center.	Observer facing along storm track. If wind shifts toward the right.	If wind shifts toward the left.	If wind steady with falling barometer.	If wind steady with rising barometer.
		Steamers bring wind on starboard bow and make as much way as possible; if obliged to heave to, do so head to sea. Sailing vessels haul by wind on starboard tack and carry sail as long as possible; if obliged heave to, do so on starboard tack.	Hold course [a] as long as possible; if obliged to heave to, do so on port tack.	Hold course as long as possible; if obliged to heave to, do so on port tack.	Hold course [a] as long as possible; if obliged to heave to, do so on starboard tack.
North.	ESE.		Run SSW.	Run SSW.	Run SSW.
NNE.	SE.		Run SW.	Run SW.	Run SW.
NE.	SSE.		Run WSW.	Run WSW.	Run WSW.
ENE.	South.		Run West.	Run West.	Run West.
East.	SSW.		Run WNW.	Run WNW.	Run WNW.
ESE.	SW.		Run NW.	Run NW.	Run NW.
SE.	WSW.		Run NNW.	Run NNW.	Run NNW.
SSE.	West.		Run North.	Run North.	Run North.
South.	WNW.		Run NNE.	Run NNE.	Run NNE.
SSW.	NW.		Run NE.	Run NE.	Run NE.
SW.	NNW.		Run ENE.	Run ENE.	Run ENE.
WSW.	North.		Run East.	Run East.	Run East.
West.	NNE.		Run ESE.	Run ESE.	Run ESE.
WNW.	NE.		Run SE.	Run SE.	Run SE.
NW.	ENE.		Run SSE.	Run SSE.	Run SSE.
NNW.	East.		Run South.	Run South.	Run South.

[a] Courses given are for wind two points on starboard quarter, but it is preferable to take wind broad on quarter if possible.

Storm Table, Southern Hemisphere.

Direction of wind.	Direction of center.	Observer facing along storm track. If wind shifts toward the right.	If wind shifts toward the left.	If wind steady with falling barometer.	If wind steady with rising barometer.
		Hold course [a] as long as possible; if obliged to heave to, do so on starboard tack.	Steamers bring wind on port bow and make as much way as possible; if obliged to heave to, do so head to sea. Sailing vessels haul by wind on port tack, and carry sail as long as possible; if obliged to heave to, do so on port tack.	Hold course as long as possible; if obliged to heave to, do so on starboard tack.	Hold course [a] as long as possible; if obliged to heave to, do so on port tack.
North.	WSW.	Run SSE.		Run SSE.	Run SSE.
NNE.	West.	Run South.		Run South.	Run South.
NE.	WNW.	Run SSW.		Run SSW.	Run SSW.
ENE.	NW.	Run SW.		Run SW.	Run SW.
East.	NNW.	Run WSW.		Run WSW.	Run WSW.
ESE.	North.	Run West.		Run West.	Run West.
SE.	NNE.	Run WNW.		Run WNW.	Run WNW.
SSE.	NE.	Run NW.		Run NW.	Run NW.
South.	ENE.	Run NNW.		Run NNW.	Run NNW.
SSW.	East.	Run North.		Run North.	Run North.
SW.	ESE.	Run NNE.		Run NNE.	Run NNE.
WSW.	SE.	Run NE.		Run NE.	Run NE.
West.	SSE.	Run ENE.		Run ENE.	Run ENE.
WNW.	South.	Run East.		Run East.	Run East.
NW.	SSW.	Run ESE.		Run ESE.	Run ESE.
NNW.	SW.	Run SE.		Run SE.	Run SE.

[a] Courses given are for wind two points on port quarter, but it is preferable to take wind broad on quarter if possible.

488. Extra-Tropical Cyclonic Storms.—On turning to the cyclones of temperate latitudes, we find many features in which they resemble those of the torrid zone, but certain other features in which they differ. Their fundamental resemblance to tropical cyclones is seen in their incurving winds, forming an inflowing left-handed spiral about the center of low pressure in the northern hemisphere, an inflowing right-handed spiral in the southern. The intensity of these winds varies with the depth of the barometric depression. The depression itself, however, in place of covering a few miles, as is the case in the tropics, will frequently have a diameter of several hundred or even a thousand miles, and for some distance around the center the gradients will have a tolerably strong value. For this reason there is less concentration of violence close to the center, and the calm and clear central space, or "eye," is seldom sharply developed, although it is not uncommon to discover a gradual weakening or failing

of the winds, and sometimes even an imperfect breaking away of the clouds as the central area passes over the observer. The form of tropical cyclones as defined by their isobaric lines is nearly circular. Extra-tropical cyclones are as a rule less symmetrical, and their isobars are often elongated into an oval form, the longer axis of the oval trending (in the northern hemisphere) between north and east—about, therefore, in the direction of progression. The steepest gradients, and consequently the strongest winds, are apt to be found on the equatorial and westerly sides of the depression.

Extra-tropical cyclones generally follow an easterly course, inclining somewhat toward the pole; but they occasionally turn to one side or the other, become stationary, or even move backward. The velocity of progression varies from 15 to 40 miles an hour. If they exist as independent barometric depressions, with strong upward gradients on all sides of the center, the cyclonic circulation will be complete, the wind shifting with the sun for an observer situated in the equatorial semicircle of the storm, against the sun for an observer situated in the polar semicircle.

Important among these extra-tropical cyclonic disturbances are the pamperos of the Argentine coast. These storms are primarily caused by the approach and passage eastward of an area of low pressure, around which the winds circulate spirally in a right-handed direction. They vary in strength and duration from a squall to a gale of great violence. Although preceded by the indications which characterize the approach of cyclonic storms in general, yet they usually break with such suddenness, in a shift of wind from the northward to the southwestward, that they may become particularly dangerous from this cause alone. They usually continue to blow and die out in the southwest quadrant.

489. Storms Along the Transatlantic Steamship Routes.—The storms which are so frequently met during the winter season along the steamship routes between America and Europe are not, as a rule, due to central barometric depressions but to depressions having a trough or V shape, which extend southerly from the extensive permanent area of low pressure having its center in the vicinity of Iceland. They are not attended by complete cyclonic circulations, inasmuch as the polar gradients which would otherwise give rise to easterly winds on this polar side are lacking. Their approach is heralded by a gradual hauling of the wind to southward, which is later followed (at the time of passage of the central line of the trough) by a change to NW., accompanied by heavy rain squalls and a rapid increase in force. The general distribution of pressure and the surrounding winds are shown in figure 76.

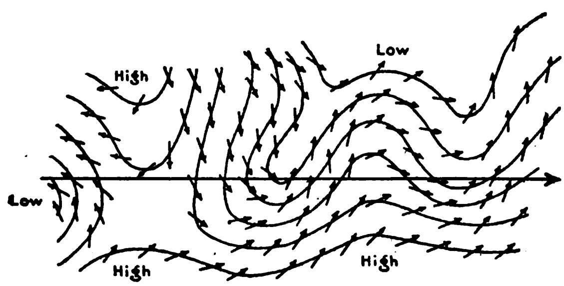


Fig. 76.

The changes in wind and pressure ensue much more rapidly in the case of a westward-bound vessel than in that of one eastward bound, the rate at which the observer and the depression approach each other being in the former case the sum of his own westward velocity and the eastward velocity of the trough, in the latter case the difference of these velocities.

CHAPTER XX.

TIDES.

490. DEFINITIONS.—Tidal phenomena present themselves to the observer under two aspects—as alternate elevations and depressions of the sea, and as recurrent inflows and outflows of streams. The word *tide*, in common and general usage, is made to refer without distinction to both the vertical and horizontal motions of the sea, and confusion has sometimes arisen from this double application of the term; in its strict sense, this word may be used only with reference to the changes of elevation, while the recurrent streams are properly distinguished as *tidal currents*.

The tide rises until it reaches a maximum height called *high water* or *high tide*, and then falls to a minimum level called *low water* or *low tide*; that period at high or low water marking the transition between the tides, during which no vertical change can be detected, is called *stand*.

Of the tidal currents, that which arises from a movement of the water in a direction, generally speaking, from the sea toward the land, is called *flood*, and that arising from an opposite movement, *ebb;* the intermediate period between the currents, during which there is no horizontal motion, is distinguished as *slack*. *Set* and *drift* are terms applicable to the tidal currents, the first referring to the direction and the second to the velocity.

Care should be taken to avoid confusing the terms relating to tides with those which relate to tidal currents.

491. CAUSE.—The cause of the tides is the periodic disturbance of the ocean from its position of equilibrium brought about through the periodic differences of attraction upon the water particles of the earth, by the moon, and to lesser degree, by the sun, on account of their relative periodic movements. The tide-producing force of the moon upon a particle of unit mass on the surface of the earth is the difference between the moon's attraction upon the given unit mass and the moon's attraction upon the entire earth; and it is likewise with the sun, only the magnitude of the mean tide-producing force is in this case reduced to about two-fifths of the tide-producing force of the moon, because of the comparative remoteness of the sun from the earth.

A particle which has a tide-producing body in its zenith or in its nadir experiences, as the result of the attraction of the tide-producing body, an effect only in the vertical direction as if the intensity of gravity were momentarily lessened; and a particle which has the tide-producing body in its horizon, being then practically at the same distance from the tide-producing body as the center of the earth, experiences, as the result of the attraction of the tide-producing body, an effect which is practically all in the vertical direction as if the intensity of gravity were momentarily increased. But when the tide-producing body is in any other situation with reference to an attracted particle, the attraction is partly directed in a vertical line toward the center of the earth and partly in a horizontal direction along the surface of the earth. The vertical components of the attractions of the tide-producing bodies can not create any sensible disturbance on the existing oceans; but the horizontal components of such attractions, tending to produce horizontal movements oscillating back and forth on the surface of the earth, are effective in the production of the tides, and, by acting upon portions of the oceans that are susceptible of taking up stationary oscillations in approximate unison with the period of the tide-producing forces, give rise to the dominant tides.

The peculiarities that characterize the tides of many localities are caused by modifications resulting from reflections and interferences suffered by the dependent waves generated by the dominant tides. Theory is not yet sufficiently advanced to render practicable the prediction of the tides where no observations have been made;

but by theory, supplemented by the observation of actual tidal conditions in a given locality during a certain period of time, very accurate predictions of the time and height of the tides can be made for that locality.

492. ESTABLISHMENT.—High and low water occur, on the average of the twenty-eight days comprising a lunar month, at about the same intervals after the transit of the moon over the meridian. These nearly constant intervals, expressed in hours and minutes, are known, respectively, as the *high water lunitidal interval* and *low water lunitidal interval.*

The interval between the moon's meridian passage at any place and the time of the next succeeding high water, as observed on the days when the moon is at full or change, is called the *vulgar* (or *common*) *establishment* of that place, or, sometimes, simply the *establishment.* This interval is frequently spoken of as the *time of high water on full and change days* (abbreviated "H. W. F. & C."); for since, on such days, the moon's two transits (upper and lower) over the meridian occur about midnight and noon, the vulgar establishment then corresponds closely with the local times of high water. When more extended observations have been made, the average of all high water lunitidal intervals for at least a lunar month is taken to obtain what is termed, in distinction to the vulgar establishment, the *corrected establishment* of the port, or *mean high water lunitidal interval.* In defining the tidal characteristics of a place some authorities give the corrected establishment, and others the vulgar establishment, or "high water, full, and change;" calculations based upon the former will more accurately represent average conditions, though the two intervals seldom differ by a large amount.

Having determined the time of high water by applying the establishment to the time of moon's transit, the navigator may obtain the time of low water with a fair degree of approximation by adding or subtracting $6^h\ 13^m$ (one-fourth of a mean lunar day); but a closer result will be given by applying to the time of transit the *mean low water lunitidal interval,* which occupies the same relation to the time of low water as the mean high water lunitidal interval, or corrected establishment, does to the time of high water.

493. RANGE.—The *range* of the tide is the difference in height between low water and high water. This term is often applied to the difference existing under average conditions, and may in such a case be designated as the *mean range* or *mean rise and fall* to distinguish it from the *spring range* or *neap range,* which are the ranges at spring and neap tides, respectively.

494. SPRING AND NEAP TIDES.—At the times of new and full moon the relative positions of sun and moon are such that the high water produced by one of those bodies occurs at the same time as that produced by the other, and so also with the low waters; the tides then occurring, called *spring tides,* have a greater range than any others of the lunar month, and at such times the highest high tides as well as the lowest low tides are experienced, the tidal range being then at its maximum. At the first and third quarters of the moon the positions are such that the high tide due to one body occurs at the time of the low tide due to the other, so that the two actions are opposed; this causes the *neap tides,* which are those of minimum range, the high waters being lower and the low waters higher than at other periods of the month.

Since the horizontal motion of the water depends directly upon the rise and fall of the tides it follows that the currents will be greatest at springs and least at neaps.

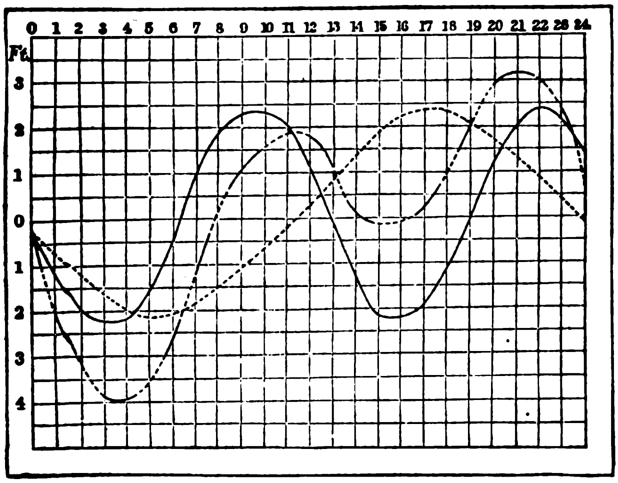
The effect of the moon's being at full or change is not felt at once in all parts of the world, and the greatest range of tides does not generally occur until one or two days thereafter; thus, on the Atlantic coast of North America, the highest tides are experienced one day, and on the Atlantic coast of Europe two days, afterwards, though on the Pacific coast of North America they occur nearly at full and change.

495. The nearer the moon is to the earth the stronger is its attraction, and as it is nearest in perigee, the tides will be larger then on that account, and consequently less in apogee. For a like reason, the tides will be increased by the sun's action when the earth is near its perihelion, about the 1st of January, and decreased when near its aphelion, about the 1st of July.

496. The height of the tides at any place may undergo modification on account of strong prevailing winds or abnormal barometric conditions, a wind blowing off the shore or a high barometric tending to reduce the tides, and the reverse. The effect of atmospheric pressure is to create a difference of about 2 inches in the height of tide for every tenth of an inch of difference in the barometer.

497. Priming and Lagging.—The *tidal day* is the variable interval, averaging 24^h 50^m, between two alternate high or low waters. The amount by which corresponding tides grow later day by day—that is, the amount by which the tidal day exceeds 24^h—is called the *daily retardation.* When the sun's tidal effect is such as to shorten the lunitidal intervals, thus reducing the length of the tidal day and causing the tides to occur earlier than usual, there is said to be a *priming* of the tide; when, from similar causes, the interval is lengthened, there is said to be a *lagging.*

498. Types of Tides.—The observed tide is not a simple wave; it is a compound of several elementary undulations, rising and falling from the same common plane, of which two can be distinguished and separated by a simple grouping of the data. These two waves are known as the *semidiurnal* and the *diurnal* tides, because the first, if alone, would give two high and two low waters in a day, while the second would give but one high and one low water in an equivalent period of time. In nearly all ports these two tides coexist, but the proportion between them varies remarkably for different seas. The effect of the combination of these two types of tide is to produce a *diurnal inequality,* both in the height of two consecutive high or low waters, and in the intervals of time between their occurrence. The height of the diurnal wave may be regarded as reaching a maximum fortnightly, soon after the moon attains its extreme declination and is therefore near one of the tropics. The tides that then occur are denominated *tropic tides.*



——— Semidiurnal. .....diurnal. ——...—— mixed.

Fig. 77.

In undertaking to investigate the tides of a port it is important to ascertain as early as possible the form of the tide; that is, whether it resembles the semidiurnal, the diurnal, or the mixed type; because not only may this information be of scientific value, but the knowledge thus gained at the outset will enable the observer to fix upon the best method of keeping his record.

499. The type forms referred to are illustrated in the diagram in figure 77, where the waves are plotted in curves, using the times as abscissæ and the heights as ordinates. In this diagram, the curve traced in the full line is a tide wave of the semidiurnal type; that traced by the dotted line one of the diurnal; while the broken line is one of the mixed type, in this case the compound of the two others.

In order to determine the type to which the tide of any port belongs, it is usually only necessary to make hourly observations for a day or two at the date of the moon's maximum declination, and to repeat the series about a week later, when the moon crosses the equator. The reported irregularities of the rise and fall at any place should not deter persons from careful investigation. When analyzed, even the most complicated of tides are found to follow some general law.

500. Tidal Currents.—It should be clearly borne in mind by the navigator that the periods of flood and ebb currents do not necessarily coincide with those of rising and falling tides, and that, paradoxical though it may seem at first thought, the inward set of the surface current does not always cease when the water has attained its maximum height, nor the outward set when a minimum height has been reached. Under some circumstances it may occur that stand and slack will be simultaneous, while other conditions may produce a maximum current at stand, with a maximum rate of rise or fall at slack water.

The varying effects which will be produced according to local conditions may be considered by the comparison of two tidal basins, to one of which the tide wave has access from the sea by a channel of ample capacity, while the other has an entrance that is narrow and constricted. In the first case, the process of filling or emptying the basin keeps pace with the change of level in the sea and is practically completed as soon as the height without becomes stationary; in this case slack and stand occur nearly at the same time, as do flood and rise and ebb and fall. In the second case, the limited capacity of the entrance will not permit the basin to fill or empty as rapidly as the tide changes its level without; hence there is still a difference of level to produce a current when the vertical motion in either direction has ceased on the outside, and for a considerable time after motion in the reverse direction has been in progress; under extreme conditions it may even occur that a common level will not be established until mid-tide, and therefore the surface current at some places will ebb until three hours after low water and flow until three hours after high water.

Localities that partake of the nature of the first case are those upon open coasts and wide-mouthed bights. Examples of the latter class will be found in narrow bays and long channels.

TIMES OF HIGH AND LOW WATER.

501. Tide Tables.—The most expeditious, as well as most exact, method of ascertaining the times of high and low water and other features of the tides will be by reference to a *Tide Table*, and every navigator is recommended to provide himself with such a publication. The United States Coast and Geodetic Survey publishes annually, in advance, tables giving, for every day in the year, the predicted time and height of the tides at certain principal ports of the world, and from these, by a simple reduction, the times and heights at a multitude of other ports may readily be obtained; data for ascertaining the tidal currents in certain important regions are also provided. General tide tables are also published by the governments of other maritime nations, and special tables are to be had for many particular localities.

502. Where no tide tables are available, the method of calculation by applying the lunitidal interval to the time of the moon's meridian passage must be resorted to.

To do this, find first the time of the moon's meridian passage, upper or lower, as may be required. The Greenwich mean time of upper transit at Greenwich is given in the Nautical Almanac; the corresponding time of lower transit is most easily found by taking the mean of the two adjacent upper transits; to the Greenwich time of Greenwich transit apply the correction for longitude given in Table 11 (using the daily variation of the moon's meridian passage shown in the Almanac), adding in west and subtracting in east longitude; the result is the local mean time of local transit. Add to this the high-water or low-water lunitidal interval of the port from Appendix IV, according as the time of high or low water may be required. The result is the time sought.

The astronomical date must be strictly adhered to, and in so doing it may be found necessary to employ the time of a lower transit, or the transit of a preceding day, to find the time of the tide in question.

Appendix IV contains, besides the geographical positions of all the more important positions in the world, a series of tidal data relating to many of those places. In such data are comprised the mean lunitidal intervals for high and low water; also, for places where the semi-diurnal type of tide prevails, the tidal range at spring and at neap tides, and for those where the tide is of the diurnal type, the tropic range. An alphabetical index is appended to this table.

The corrected establishment taken from the charts may be substituted for the high-water lunitidal interval of the table; or, with only slight variation in the results, the vulgar establishment (H. W. F. & C.) may be employed.

Example: Find the times of the high and low waters at the New York Navy Yard, occurring next after noon on April 15, 1916.

G. M. T. of Gr. upper transit,	14^d	9^h	21^m
G. M. T. of Gr. upper transit,	15	10	05
	2)29	19	26
G. M. T. of Gr. lower transit	14	21	43
Corr. for +74° Long. (Tab. 11), +			9
L. M. T. of local lower transit	14	21	52

Transit (lower),	14^d	21^h	52^m
H. W. Lun. Int. (App. IV),		8	44
L. M. T., H. W.,	15	6	36
	Apr. 15, 6.36 p. m.		

Transit (lower),	14^d	21^h	52^m
L. W. Lun. Int. (App. IV),		2	49
L. M. T., L. W.,	15	0	41
	Apr. 15, 12.41 p. m.		

Example: Find the time of high water at the Presidio, San Francisco, Cal., on the evening of February 17, 1916.

G. M. T. of Gr. upper transit,		16^d	10^h	37^m
G. M. T. of Gr. upper transit,		17	11	23
		2)33	22	00
G. M. T. of Gr. lower transit,		16	23	00
Corr. +122° Long. (Tab. 11),	+			16
L. M. T. local lower transit,		16	23	16
H. W. Lun. Int. (App. IV),			11	43
L. M. T., H. W.,		17	10	59
		Feb. 17, 10.59 p. m.		

Example: Find the time of low water at Singapore on the night of May 21, 1916.

G. M. T. of Gr. upper transit,		20^d	15^h	29^m
G. M. T. of Gr. upper transit,		21	16	28
		2)42	7	57
G. M. T. of Gr. lower transit,		21	3	59
Corr. for −104° Long. (Tab. 11),	−			17
L. M. T. of local lower transit,		21	3	42
L. W. Lun. Int. (App. IV)	+		4	02
L. M. T., L. W.,		21	7	44
		May 21, 7.44 p. m.		

Example: Find the time of morning high water and afternoon low water at Gibraltar on June 19, 1916.

G. M. T. of Gr. upper transit,		18^d	15^h	12^m
Corr. +5° Long. (Tab. 11),	+			01
L. M. T. of local transit,		18	15	13
H. W. Lun. Int. (App. IV),			1	35
L. M. T., H. W.,		18	16	48
		June 19, 4.48 a. m.		

G. M. T. of Gr. upper transit,		18^d	15^h	12^m
G. M. T. of Gr. upper transit,		19	16	05
		2)38	7	17
G. M. T. of Gr. lower transit,		19	3	39
Corr. for +5° Long. (Tab. 11),	+			01
L. M. T. of local lower transit,		19	3	40
L. W. Lun. Int. (App. IV),			7	55
L. M. T., L. W.,		19	11	35
		June 19, 11.35 p. m.		

TIDAL OBSERVATIONS.

503. Since navigators will frequently have opportunity to observe tidal conditions, either in connection with a hydrographic survey or otherwise, at places where existing knowledge of the tides is incomplete, an understanding of the methods employed in tidal observations may be important.

504. Tides.—For the proper study of tides, frequent and continuous observations are necessary; it will not suffice to observe the heights of the high and low waters only, even if they present themselves as distinct phases, but the whole tidal curve for each day should be developed by recording the height of water at intervals, which, preferably, should not exceed thirty minutes. Observations, to be complete, must cover a whole lunar month; or, if it be impracticable to observe the tides at night, the day tides of two lunar months may be substituted.

505. When made for the purposes of a hydrographic survey, the tidal observations are used to correct the soundings, and care must be taken to make sure that the gauge is placed in a situation visited by the same form of tide as that which occurs at the place where soundings are being made. It will not answer, for instance, to correct the soundings upon an inlet bar by tidal observations made within the lagoon with which this inlet communicates, because the range of the tide within the lagoon is less than upon the outside coast. A partial obstruction, like a bridge, or a natural contraction of the channel section, while it may not reduce the total range of the tide or materially affect the time of high or low tides, will alter the relative heights above and below at intermediate stages, so that the hydrographer must be careful to see that no such obstruction intervenes between his field of work and the gauge.

506. TIDAL CURRENTS.—Observations for tidal currents should be made with the same regularity as for tides; the intervals need not ordinarily be more frequent than once in every half hour. They should always be made at the same point or points, which should be far enough from shore to be representative of the conditions prevailing in the navigable waters. The ordinary log may be employed for measuring the current, but it is better to replace the chip by a pole weighted to float upright at a depth of about fifteen feet; the line should be a very light one, and buoyed at intervals by cork floats to keep it from sinking; the set of the current should be noted by a compass bearing of the direction of the pole at the end of the observation.

507. RECORD.—The record of observations should be kept clearly and in complete form. It should include a description of the locality of observation, the nature of gauge and of instruments used for measuring currents, and the exact position of both tidal and current stations, together with situation and height of bench mark. The time of making each observation should be shown, and data given for reduction to some standard time. In extended tidal observations the meteorological conditions should be carefully recorded, the instruments used for the observations being properly compared with standards.

508. There are frequently remarkable facts in reference to tides and currents to be obtained from persons having local knowledge; these should be examined and recorded. The date and circumstances of the highest and lowest tides ever known form important items of information.

509. PLANES OF REFERENCE.—The *plane of reference* is the plane to which soundings and tidal data are referred. One of the principal objects of observing tides when making a survey is to furnish the means for reducing the soundings to this plane. Four planes of reference are used; namely, mean low water, mean low water springs, mean lower low waters, and the harmonic or Indian tide plane.

Mean low water is a plane whose depression below mean sea level corresponds with half the mean semidiurnal range, while the depression of *mean low water springs* corresponds with half the mean range of spring tide; *mean lower low water* depends upon the diurnal inequality in high and low water; the *harmonic* or *Indian tide plane* was adopted as a convenient means of expressing something of an approximation to the level of low water of ordinary spring tides, but where there is a large diurnal inequality in low waters it falls considerably below the true mean of such tides.

As these planes may differ considerably, it is important to ascertain which plane of reference is adopted before making use of any chart or considering data concerning the tides.

510. The tides are subject to so many variations dependent upon the movements of the sun and moon, and to so many irregularities due to the action of winds and river outflows, that a very long series of observations would be necessary to fix any natural plane. In consideration of this, and keeping in view the possibilities of repetitions of the surveys or subsequent discoveries within the field of work, it is necessary to define the position of the plane of reference which has resulted from any series of observations. This is done by leveling from the tide gauge to a permanent *bench*, precisely as if the adopted plane were arbitrary.

511. BENCH MARK.—The plinth of a lighthouse, the water table of a substantial building, the base of a monument, and the like, are proper benches; and when these are not within reach a mark may be made on a rock not likely to be moved or started by the frost, or, if no rock naturally exists in the neighborhood, a block of stone buried below the reach of frost and plowshare should be the resort. When a bench is made on shore it should be marked by a circle of 2 or 3 inches diameter with a cross in the center indicating the reference point. The levelings between this point and the gauge should be run over twice and the details recorded. A bench made upon a wharf or other perishable structure is of little value, but in the absence of permanent objects it is better than nothing. The marks should be cut in, if on stone, and if on wood, copper nails should be used. The bench must be sketched and carefully described, and its location marked on the hydrographic sheet, with a statement of the relative position of the plane of reference.

512. The leveling from the bench mark to the tide gauge may be done, when a leveling instrument is not available, by measuring the difference of height of a number of intermediate points by means of a long straight-edged board, held horizontal by the aid of a carpenter's spirit level, or even a plummet square, taking care to repeat each step with the level inverted end for end. A line of sight to the sea horizon, when it can be seen from the bench across the tide staff, will afford a level line of sufficient accuracy, especially when observed with the telescope. It may often be convenient to combine these methods.

513. Tide Gauges.—The *Staff Gauge* is the simplest device for measuring the heights of tides, and in perfectly sheltered localities it is the best. It consists of a vertical staff graduated upward in feet and tenths, and so placed that its zero shall lie below the lowest tides. The same gauge may also be used where the surface is rough, if a glass tube with a float inside is secured alongside of the staff, care being taken to practically close the lower end of the tube so as to exclude undulations; readings may also be made by noting the point midway between the crest and trough of the waves.

A staff gauge should always be erected for careful tidal observations, even where other classes of gauge are to be employed, as it furnishes a standard for comparison of absolute heights, and also serves to detect any defects in the mechanical details upon which all other gauges are to a greater or less extent dependent.

514. Where there is considerable swell, and where, from the situation of the gauge or the great range of the tide (making it inconvenient for the observer to see the figures in certain positions) the staff gauge can not be used, recourse must be had to the *Box Gauge*. This gauge consists of a vertical box, closed at the bottom, with a few small holes in the lower part which admit sufficient water to keep the level within equal to the mean level without but which do not permit the admission of water with sufficient rapidity to be affected by the waves. Within the box is a copper float; in some cases this float carries a graduated vertical rod whose position with reference to a fixed point of the box affords a measure for the height of the water; in other gauges of this class the float is attached to a wire or cord which passes over pulleys and terminates in a counterpoise whose position on a vertical graduated scale shows the height of tide.

515. An *Automatic Gauge* requires a box and float such as has just been described. The motion of the float in rising and falling with the tide is communicated to a pencil which rests upon a moving sheet of paper; uniform motion is imparted to the paper by the revolution of a cylinder driven by clockwork; the motion of the pencil due to the tide is in a direction perpendicular to the direction of motion of the paper, and a curve is thus traced, of which one coordinate is time and the other height. The paper, which is usually of sufficient length to contain a month's record, is paid out from one cylinder, passes over a second whereon it receives the record and is rolled upon a third cylinder, which thus contains the completed tidal sheet.

This gauge, besides giving a perfectly continuous record, has the further merit of requiring but little of the observer's time. But its indications, both of time and heights, should be checked by occasional comparisons with the standard clock and the staff gauge, the readings of which should be noted by hand at appropriate points of the graphic record.

A newer type of automatic gauge prints the date, the time, and the stage of the tide every five minutes on a paper tape.

CHAPTER XXI.

OCEAN CURRENTS.

516. An *ocean current* is a progressive horizontal motion of the water occurring throughout a region of the ocean, as a result of which all bodies floating therein are carried with the stream.

The *set* of a current is the direction toward which it flows, and its *drift*, the velocity of the flow.

517. CAUSE.—The principal cause of the superficial ocean currents is the wind. Every breeze sets in motion, by its friction, the surface particles of the water over which it blows; this motion of the upper stratum is imparted to the stratum next beneath, and thus the general movement is communicated, each layer of particles acting upon the one below it, until a current is established. The direction, depth, strength, and permanence of such a current will depend upon the direction, steadiness, and force of the wind; all, however, subject to modification on account of extraneous causes, such as the intervention of land or shoals and the meeting of conflicting currents.

A minor cause in the generation of ocean currents is the difference in density of the sea water in different regions, as a result of which a set is produced from the more dense toward the less dense, in the effort to establish equilibrium of pressure; the difference of density may be due to temperature, the warmer water near the equator being less dense than the colder water of higher latitudes; or it may be created by a difference in the amount of contained saline matter, resulting from evaporation, freezing, or other causes. Another minor factor that may have influence upon ocean currents is the difference of pressure exerted by the atmosphere upon the water in different regions. But neither of the last-mentioned causes may be regarded as of great importance when compared with the influence, direct and indirect, of the wind.

518. SUBMARINE CURRENTS.—In any scientific investigation of the circulation of ocean waters it is necessary to take account of the submarine currents as well as those encountered upon the surface; but for the practical purposes of the navigator the surface currents alone are of interest.

519. METHODS OF DETERMINATION.—The methods of determining the existence of a current, with its set and drift, may be divided into three classes; namely, (*a*) by observations from a vessel occupying a stationary position not affected by the current; (*b*) by comparison of the position of a vessel under way as given by observation with that given by dead reckoning; and (*c*) by the drift of objects abandoned to the current in one locality and reappearing in another.

520. Of these methods the first named, by observations from a vessel at anchor, is by far the most accurate and reliable, but being possible only under special circumstances is not often available. The most valuable information about ocean currents being that which pertains to conditions in the open sea, the great depths there existing usually preclude the possibility of anchoring a vessel; ships especially fitted for the purpose have at times, however, carried out current observations with excellent results; the most notable achievements in this direction are those of the survey of the Gulf Stream, made by United States naval officers acting under the Coast and Geodetic Survey, during which the vessel was anchored and observations were made in positions where the depths reached to upward of 2,000 fathoms.

521. The method of determining current from a comparison of positions obtained respectively by observation and by dead reckoning is the one upon which our knowledge must largely depend. This method is, however, always subject to some inaccuracy, and the results are frequently quite erroneous, for the so-called current is thus made to embrace not only the real set and drift, but also the errors of observation and dead reckoning. In the case of a modern steamer accurately steered and equipped with good instruments for determining the speed through the water as well as the position by astronomical observations, the current may be arrived at by this method with a fairly close degree of accuracy. It is not always possible, however, to keep an exact reckoning, and this is especially true in sailing vessels, where the conditions render it difficult to determine correctly the position by account; this source of error may be combined with faulty instrumental determinations, giving apparent currents differing widely from those that really exist.

522. Much useful knowledge regarding ocean currents has been derived from the observed drift of objects from one to another locality. This is true not only of the bottles thrown overboard from vessels with the particular object of determining the currents, but also of derelicts, drifting buoys, and pieces of wreckage, which fulfill a similar mission. The deductions to be drawn from such drift are of a general nature only. The point of departure, point of arrival, and elapsed time are all that are positively known. The route followed and the set and drift of current at different points are not indicated, and in the case of objects floating otherwise than in a completely submerged condition account must be taken of the fact that the drift is influenced by the wind. But even this general information is of great value in researches as to ocean currents, and navigators who desire to aid in the work of investigation may do so by throwing overboard, from time to time, sealed bottles containing a statement of date and position at which they are launched.

523. Currents of the Atlantic Ocean.—A consideration of the currents of the Atlantic most conveniently begins with a description of the *Equatorial Currents*. The effect of the northeast and southeast trade winds is to form two great drift currents, setting in a westerly direction across the Atlantic from Africa toward the American continent, whose combined width covers at times upward of fifty degrees of latitude. These are distinguished as the *Northern* or *Southern Equatorial Currents*, according as they rise from the trade winds of the northern or southern hemisphere.

Of the two, the Southern Equatorial Current is the more extensive. It has its origin off the continent of Africa south of the Guinea coast, and begins its flow with a daily velocity that averages about 15 miles; it maintains a general set of west, the portion near the equator acquiring later, however, a northerly component, while the drift steadily increases until, on arriving off the South American coast, a rate of 60 miles is not uncommon. At Cape San Roque the current bifurcates, the main or equatorial branch flowing along the Guiana coast, while the other branch is deflected to the southward.

The Northern Equatorial Current originates to the northward of the Cape Verde Islands and sets across the ocean in a direction that averages due west; though parallel to the corresponding southern drift, its velocity is not so high.

524. Between the Northern and Southern Equatorial Currents is found the *Equatorial Counter Current* setting to the eastward under the propelling force of the southwest monsoon, which prevails over an elongated area of varying extent lying north of the equator and stretching westward from the southwestern part of the salient extension of the continent of Africa. The extent and strength of this current thus varies with the seasonal extent of the monsoon area, being a maximum in July and August, when its effect is apparent to the westward of the fiftieth meridian of west longitude, while at its minimum, in November and December, its influence is but slight and prevails for only a limited distance from the African coast.

525. To the westward of the region of the Equatorial Counter Current the North and the South Equatorial Currents unite. A large part of the combined stream flows into the Caribbean Sea through the various passages between the Windward Islands, takes up a course first to the westward and then to the northward and westward, finally arriving off the extremity of the peninsula of Yucatan; from here some of the water follows the shore line of the Gulf of Mexico, while another portion passes directly toward the north Cuban coast; by the reuniting of these two branches in the Straits of Florida there is formed the most remarkable of all ocean currents—the Gulf Stream.

From that portion of the combined equatorial currents which fails to find entrance to the Caribbean Sea a current of moderate strength and volume takes its course along the north coasts of Porto Rico, Haiti, and Cuba, flows between the last-named island and the Bahamas, and enters the Gulf Stream off the Florida coast, thus adding its waters to those of the main branch of the Equatorial Current which have arrived at the same point by way of the Caribbean, the Yucatan Passage, and the Gulf.

526. The *Gulf Stream,* which has its origin, as has been described, in the Straits of Florida, and receives an accession from a branch of the Equatorial Current off the Bahamas, flows in a direction that averages true north as far as the parallel of

31°, then curves sharply to ENE. until reaching the latitude of 32°, when a direction a little to the north of NE. is assumed and maintained as far as Cape Hatteras; at this point its axis is about 40 miles, while its inner edge is in the neighborhood of 20 miles off the shore. Thus far in its flow the average position of the maximum current is from 11 to 20 miles outside the 100-fathom curve, disregarding the irregularities of the latter, and the width of the stream—about 40 miles—is nearly uniform. From off Hatteras the stream broadens rapidly and curves more to the eastward, seeking deeper water; its northern limit may be stated to be 60 to 80 miles off Nantucket Shoals and 120 to 150 miles to the southward of Nova Scotia, in which latter place it has expanded to a width of about 250 miles. Farther on its identity as the Gulf Stream is lost, but its general direction is preserved in a current to be described later.

The water of the Gulf Stream is of a deep indigo-blue color, and its junction with ordinary sea water may be plainly recognized; in moderate weather the edges of the stream are marked by ripples; in cool regions the evaporation from its surface, due to difference of temperature between air and water, is apparent to the eye; the stream carries with it a quantity of weed known as "gulf weed," which is familiar to all who have navigated it waters.

In its progress from the tropics to higher latitudes the transit is so rapid that time is not given for more than a partial cooling of the water, and it is therefore found that the Gulf Stream is very much warmer than the neighboring waters of the seas through which it flows. This warm water is, however, divided by bands of markedly cooler water which extend in a direction parallel to the axis and are usually found near the edges of the stream of warm water. The most abrupt change from warm to cold water occurs on the inshore side, where the name of the *Cold Wall* has been given to that band which has appeared to some oceanographers to form the northern and western boundary of the stream.

The investigations of Pillsbury tend to prove that the thermometer is only an approximate guide to the direction and velocity of the current. Though it indicates the limits of the stream in a general way, it must not be assumed that the greatest velocity of flow coincides with the highest temperature, nor that the northeasterly set will be lost when the thermometer shows a region of cold sea water.

The same authority has also demonstrated that in the vicinity of the land there is a marked variation in the velocity of current at different hours of the day, which may amount to upward of 2 knots, and which is due to the elevation and depression of the sea as a result of tidal influences, the maximum current being encountered at a period which averages about three hours after the moon's transit. Another effect noted is that at those times when the moon is near the equator the current presents a narrow front with very high velocity in the axis of maximum strength, while at periods of great northerly or southerly declination the front broadens, the current decreasing at the axis and increasing at the edges. These tidal effects are not, however, observed in the open sea.

The velocity of the Gulf Stream varies with the seasons, following the variation in the intensity of the trade winds, to which it largely owes its origin. The drift of the current under average conditions may be stated as follows:

Between Key West and Habana: Mean surface velocity in axis of maximum current, 2½ knots; allowance to be made by a vessel crossing the entire width of the stream, 1.1 knots per hour.

Off Fowey Rocks: Mean surface velocity in axis, 3.5 knots; allowance in crossing, 2½ knots per hour.

Off Cape Hatteras: Mean surface velocity in axis, upward of 2 knots; allowance in crossing the stream, 1½ knots per hour between the 100-fathom curve and a point 40 miles outside that curve.

527. After passing beyond the longitude of the easternmost portions of North America, it is generally regarded that the Gulf Stream, as such, ceases to exist; but by reason of the prevalence of westerly winds the direction of the set toward Europe is continued until the continental shores are approached, when the current divides, one branch going to the northeastward and entering the Arctic regions and the other running off toward the south and east in the direction of the African coast. These currents have received, respectively, the designations of the *Easterly, Northeast,* and *Southeast Drift Currents.*

528. The effect of the currents thus far described is to create a general circulation of the surface waters of the North Atlantic, in a direction coinciding with that of the hands of a watch, about the periphery of a huge ellipse, whose limits of latitude may be considered as 20° N. and 40° N., and which is bounded in longitude by the eastern and western continents. The central space thus inclosed, in which no well-marked currents are observed, and in the waters of which great quantities of the Sargasso or gulf weed are encountered, is known as the *Sargasso Sea.*

529. The Southeast Drift Current carries its waters to the northwest coast of Africa, whence they follow the general trend of the land from Cape Spartel to Cape Verde. From this point a large part of the current is deflected to the eastward close along the upper Guinea coast. The stream thus formed, greatly augmented at certain seasons by the prevailing monsoon and by the waters carried eastward with the Equatorial Counter Current, is called the *Guinea Current.* A remarkable characteristic of this current is the fact that its southern limit is only slightly removed from the northern edge of the west-moving Equatorial Current, the effect being that the two currents flow side by side in close proximity, but in diametrically opposite directions.

530. The *Arctic* or *Labrador Current* sets out of Davis Strait, flows southward down the coasts of Labrador and Newfoundland, and thence southwestward past Nova Scotia and the coast of the United States, being found inshore of the Gulf Stream. It brings with it the ice so frequently met at certain seasons off Newfoundland.

531. *Rennells Current* was formerly represented as a temporary but extensive stream setting at times from the Bay of Biscay toward the west and northwest across the English Channel and to the westward of Cape Clear. The most recent investigations fail to reveal such a feature, but disclose only a narrow current of reaction moving northward along the coast of France when the winds have forced the waters above the usual level at the head of the Gulf of Gascoyne.

532. Of the two branches of the Southern Equatorial Current which are formed by its bifurcation off Cape San Roque, the northern one, setting along the coasts of northeastern Brazil and of Guiana and contributing to the formation of the Gulf Stream, has already been described; the other, known as the *Brazil Current,* flows to south and west, along the southeastern coast of Brazil, as far as the neighborhood of the island of Trinidad; here it divides, one part continuing down the coast and having some slight influence as far as the latitude of 45° S., and the other curving around toward east.

533. The last-mentioned branch of the Brazil Current is called the *Southern Connecting Current* and flows toward the African coast in about the latitude of Tristan da Cunha. It then joins its waters with those of the general northerly current that sets out of the Antarctic region, forming a current which flows to the northward along the southwest African coast and eventually connects with the Southern Equatorial Current, thus completing the surface circulation of the South Atlantic.

534. There is another current whose effects are felt in the Atlantic. It originates in the Pacific and flows around Cape Horn, and will be described in connection with the currents of the Pacific Ocean.

535. Currents of the Pacific Ocean.—As in the Atlantic, the waters of the Pacific Ocean, in the region between the tropics, have a general drift toward the westward, due to the effect of the trade winds, the currents produced in the two hemispheres being denominated, respectively, the *Northern* and the *Southern Equatorial Currents.* These are separated, as also in the case of the Atlantic, by an east-setting stream, about 300 miles wide, whose mean position is a few degrees north of the equator, and which receives the name of the *Equatorial Counter Current.*

536. The major portion of the Northern Equatorial Current, after having passed the Marianas, flows toward the eastern coast of Taiwan in a WNW. direction, whence it is deflected northward, forming a current which is sometimes called the *Japan Stream,* but which more frequently receives its Japanese name of Kuroshiwo, or "black stream." This current, the waters of which are dark in color and contain a variety of seaweed similar to "gulf weed," carries the warm tropical water at a rapid rate to the northward and eastward along the coasts of Asia and its offlying islands, presenting many analogies to the Gulf Stream of the Atlantic.

The limits and volume of the Kuroshiwo vary according to the monsoon, being augmented during the season of southwesterly winds and diminished during the prevalence of those from northeast. The current sets to the north along the east coast of Taiwan (Formosa), and in about latitude 26° N. changes its course to northeast, arriving at the extreme southwestern point of Japan by a route to westward of the Sakishima and Nansei Shoto. A branch makes off from the main stream to follow northward along the west coast of Japan, entering the Sea of Japan by the Tsushima Kaikyo; but the principal current bends toward the east, flows through Osumi Kaikyo and the passages between the Tokara Gunto, and runs parallel to the general trend of the south shores of the Japanese islands of Kiushu, Shikoku, and Honshu, attaining its greatest velocity between Bungo Suido and Kii Suido, where its average drift is between 2 and 3 knots per hour. Continuing beyond the southeastern extremity of Honshu, the direction of the stream becomes somewhat more northerly, and its width increases, with consequent loss of velocity. In the Kuroshiwo, as in the Gulf Stream, the temperature of the sea water is an approximate, though not an exact, guide as to the existence of the current.

537. Near 146° or 147° E. and north of the fortieth parallel the Kuroshiwo divides into two parts. One of these, called the *Kamchatka Current*, flows to the northeast in the direction of the Aleutian Islands, and its influence is felt to a high latitude. The second branch continues as the main stream, and maintains a general easterly direction to the 180th meridian, where it is merged into the north and northeast drift currents which are generally encountered in this region.

538. A cold countercurrent to the Kamchatka Current sets out of Bering Sea and flows to the south and west close to the shores of the Kuril Islands, Hokushu and Honshu, sometimes, like the Labrador Current in the Atlantic, bringing with it quantities of Arctic ice. This is often called by its Japanese name of Oyashiwo.

539. On the Pacific coast of North America, from about 50° N. to the mouth of the Gulf of California, 23° N., a cold current, 200 or 300 miles wide, flows with a mean speed of three-quarters of a knot, being generally stronger near the land than at sea. It follows the trend of the land (nearly SSE.) as far as Point Concepcion (south of Monterey), when it begins to bend toward SSW., and then to WSW., off Capes San Blas and San Lucas, ultimately joining the great northern equatorial drift.

On the coast of Mexico, from Cape Corrientes (20° N.) to Cape Blanco (Gulf of Nicoya), there are alternate currents extending over a space of more than 300 miles in width, which appear to be produced by the prevailing winds. During the dry season—January, February, and March—the currents generally set toward southeast; during the rainy season—from May to October—especially in July, August, and September, the currents set to northwest, particularly from Cosas Island and the Gulf of Nicoya to the parallel of 15°.

540. The Southern Equatorial Current prevails between limits of latitude that may be approximately given as 4° N. and 10° S., in a broad region extending from the American continent almost to the one hundred and eightieth meridian, setting always to the west and with slowly increasing velocity. In the neighborhood of the Fiji Islands this current divides; one part, known as the *Rossel Current*, continues to the westward, following a route marked by the various passages between the islands, and later acquiring a northerly component and setting through Torres Strait and along the north coast of New Guinea; the other part, called the *Australia Current*, sets toward south and west, arriving off the east coast of Australia, along which it flows southward to about latitude 35° S., whence it bends toward southeast and east and is soon after lost in the currents due to the prevailing wind.

541. The general drift current that sets to the north out of the Antarctic regions is deflected until, upon gaining the regions to the southwest of Patagonia, it has acquired a nearly easterly set; in striking the shores of the South American continent it is divided into two branches.

The first, known as the *Cape Horn Current*, maintains the general easterly direction, and its influence is felt, where not modified by winds and tidal currents, throughout the vicinity of Cape Horn, and, in the Atlantic Ocean, off the Falkland Islands and eastern Patagonia.

The second branch flows northeast in the direction of Valdivia and Valparaiso, follows generally the direction of the coast lines of Chile and Peru (though at times setting directly toward the shore in such manner as to constitute a great danger to the navigator), and forms the important current which has been called variously the *Peruvian, Chilean,* or *Humboldt Current,* the last name having been given for the distinguished scientist who first noted its existence. The principal characteristic of the Peruvian Current is its relatively low temperature. The direction of the waters between Pisco and Payta is between north and northwest; near Cape Blanco the current leaves the coast of America and bears toward the Galapagos Islands, passing them on both the northern and southern sides; here it sets toward WNW. and west; beyond the meridian of the Galapagos it widens rapidly, and the current is lost in the equatorial current, near 108° W. As often happens in similar cases, the existence of a countercurrent has been proved on different occasions; this sets toward the south, is very irregular, and extends only a little distance from shore.

542. Currents of the Indian Ocean.—In this ocean the currents to the north of the equator are very irregular; the periodical winds, the alternating breezes, and the changes of monsoon produce currents of a variable nature, their direction depending upon that of the wind which produces them, upon the form of neighboring coasts, or, at times, upon causes which can not be satisfactorily explained.

543. There is, in the Indian Ocean south of the equator, a regular *Equatorial Current* which, by reason of owing its source to the southeast trade winds, corresponds with the Southern Equatorial Currents of the Atlantic and Pacific. The limits of this west-moving current vary with the longitude as well as with the season. Upon reaching about the meridian of Rodriguez Island, a branch makes off toward the south and west, flowing past Mauritius, then to the south of Madagascar (on the meridian of which it is 480 miles broad), and thereafter, rapidly diminishing its breadth, forming part of the Agulhas Current a little to the south of Port Natal.

The main equatorial current continues westward until passing the north end of Madagascar, where, encountering the obstruction presented by the African continent, it divides, one branch following the coast in a northerly, the other in a southerly direction. The former, in the season of the southwest monsoon, is merged into the general easterly and northeasterly drift that prevails throughout the ocean from the northern limit of the Equatorial Current on the south, as far as India and the adjacent Asiatic shores on the north; but during the northeast monsoon, when there exists in the northern regions of the Indian Ocean a westerly drift current analogous to the Northern Equatorial Currents produced in the Atlantic and Pacific by the northeast trades, there is formed an east-setting *Equatorial Countercurrent,* which occupies a narrow area near the equator and is made up of the waters accumulated at the western continental boundary of the ocean by the drift currents of both hemispheres.

544. The southern branch of the Equatorial Current flows to the south and west down the Mozambique Channel, and, being joined in the neighborhood of Port Natal by the stream which arrives from the open ocean, there is formed the warm *Agulhas Current,* which possesses many of the characteristics of the Gulf and Japan streams. This current skirts the east coast of South Africa and attains considerable velocity over that part between Port Natal and Algoa Bay. During the summer months its effects are felt farther to the westward; during the winter it diminishes in force and extent. The meeting of the Agulhas Current with the cold water of higher latitudes is frequently denoted by a broken and confused sea.

Upon arriving at the southern side of the Agulhas Bank the major part of the current is deflected to the south, and then curves toward east, flowing back into the Indian Ccean with diminished strength and temperature on about the fortieth parallel of south latitude, where its influence is felt as far as the eightieth meridian. A small part of the stream which reaches Agulhas Bank continues across the southern edge of that bank before turning to the southward and eastward to rejoin the major part.

545. Along the fortieth parallel of south latitude, between Africa and Australia, there is a general easterly set, due to the branch of the Agulhas Current already described, to the continuation of the drift current from the Atlantic which passes to southward of the Cape of Good Hope, and to the westerly winds which largely prevail in this region. At Cape Leeuwin, the southwestern extremity of Australia, this east-setting current is divided into two branches; one, going north along the west coast of Australia, blends with the Equatorial Current nearly in the latitude of the Tropic of Capricorn; the other preserves the direction of the original current and has the effect of producing an easterly set along the south coast of Australia.

546. As in the other oceans, a general northerly current is observed to set into the Indian Ocean from the Antarctic regions.

CHAPTER XXII.

ICE AND ITS MOVEMENT IN THE NORTH ATLANTIC OCEAN.

547. Vessels crossing the Atlantic Ocean between Europe and the ports of the United States and British America are liable to encounter icebergs or extensive fields of compact ice, which are carried southward from the Arctic region by the ocean currents. It is in the vicinity of the Great Bank of Newfoundland that these

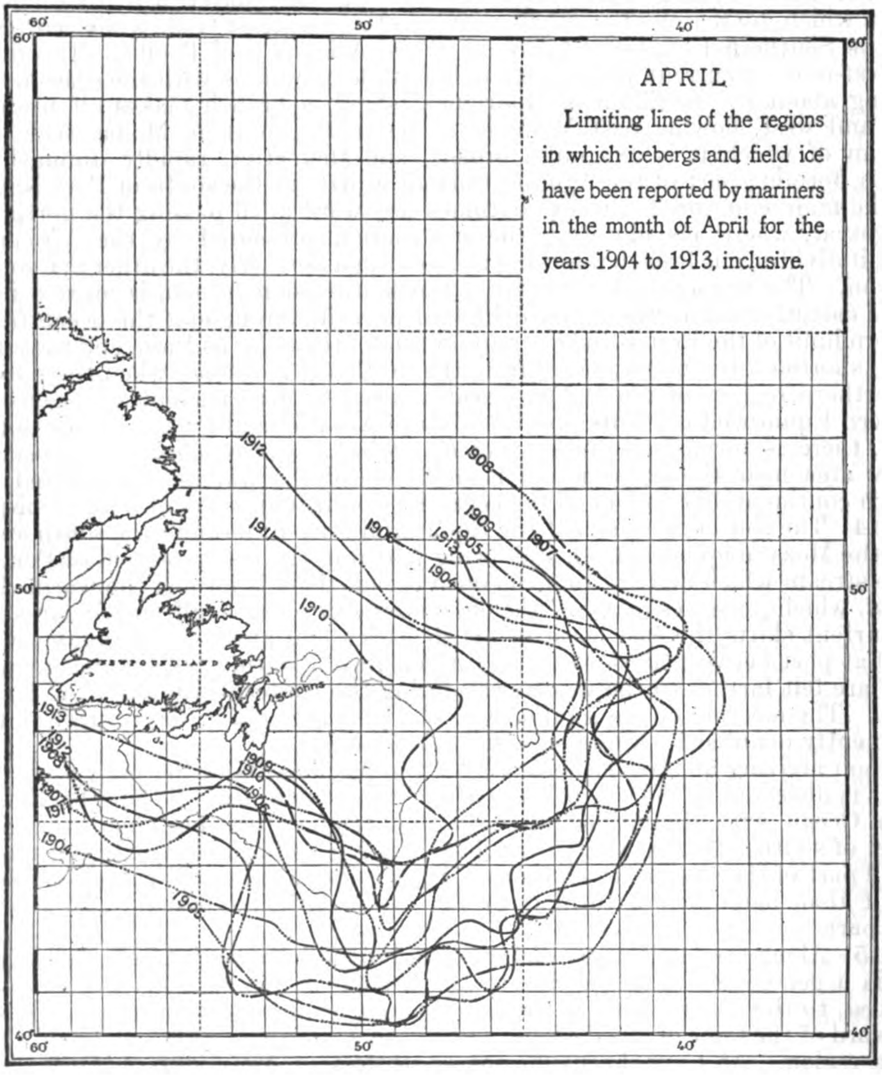


Fig. 78.

masses of ice appear in the greatest numbers and drift farthest southward. The accompanying charts show the changeable area in which icebergs and field ice have been reported by mariners in the years 1904 to 1913 in the months of April, May, and June, when they occur in the greatest number.

The amount of ice and its location and movement are so variable from year to year, while the region occupied in its formation and transportation is so vast and so little under special observation, that no successful system of prediction has as yet been instituted. The most that can be said now is that after an exceptionally open winter in the Arctic we may expect the ice to come south earlier and in greater quantity. After such a winter the East Greenland current starts the ice stream around Cape Farewell from one to three months earlier, and this advancing of the season is reflected by a corresponding advance in the Labrador Current and on the Newfoundland Bank. The greatest calving at the glaciers of Greenland follows the breaking up of the shore ice, and hence the bergs also start southward earlier and with more freedom after an open winter.

In April, May, and June, from 1904 to 1913, inclusive, icebergs have been seen as far south as latitude 37° 50′ north and as far east as longitude 38° west. Exceptional drifts have occurred almost down to latitude 30° north, and between longitudes 10° and 75° west, in these months as well as during other seasons of the year. Between Newfoundland and the fortieth parallel floating ice may be met in any month, but not often from August to December. On the Great Bank of Newfoundland bergs generally move southward. Those that drift westward of Cape Race usually pass between Green and St. Pierre banks. The Virgin Rocks are generally surrounded by ice until the middle of April or the beginning of May.

548. The Origin of the Icebergs.—Most of the bergs which annually appear in the North Atlantic originate on the western coast of Greenland; a few come from the east coast and from Hudson Bay. A small but productive glacier in southern Greenland yields the bluish bergs which are so hard to see at night. The largest bergs come from the glaciers at Umanak Fjord and Disko Bay (Lat. 69° to 71°), and their height above water will rise to 500 feet; but as they lose in mass from that time forward, we can not expect to find them of such gigantic height when they finally appear near the Newfoundland Bank.

A huge ice sheet, formed from compressed snow, covers the whole of the interior of Greenland. The surface of this enormous glacier, only occasionally interrupted by protruding mountain tops, rises slightly toward the interior and forms a watershed between the east and west coasts, which is estimated to be from 8,000 to 10,000 feet above the sea. The outskirts of Greenland, as they are called, consist of a fringe of islands, mountains, and promontories surrounding the vast ice-covered central portion and varying in width from a mere border up to 80 miles. Upon the west side, below the parallel of 73° of latitude, it has an average width of about 50 miles and extends with little interruption from Cape Farewell to Melville Bay, a distance of something over 1,000 miles.

Everywhere this mountainous belt is penetrated by deep fiords, which reach to the inland ice, and are terminated by the perpendicular fronts of huge glaciers, while in some places the ice comes down in broad projections close to the margin of the sea. All of these glaciers are making their way toward the sea, and, as their ends are forced out into the water, they are broken off and set adrift as bergs. This process is called *calving*. The size of the pieces set adrift varies greatly, but a berg from 60 to 100 feet to the top of its walls, whose spires or pinnacles may reach from 200 to 250 feet in height and whose length may be from 300 to 500 yards, is considered to be of ordinary size in the Arctic. These measurements apply to the part above water, which is about one-eighth or one-ninth of the whole mass. Many authors give the depth under water as being from eight to nine times the height above; this is incorrect, as measurements above and below water should be referred to mass and not to height.

Bergs are being formed all the year round, but in greater numbers during the summer season; and thousands are set adrift each year.

Once adrift in the Arctic they find their way into the Labrador Current and begin their journey to the southward. It is not an unobstructed drift, but one attended with many stoppages and mishaps. Many ground in the Arctic Basin and break up there; others reach the shores of Labrador, where from one end to the other they continually ground and float; some break up and disappear entirely, while others get safely past and reach the Grand Bank. The whole coast of Labrador is cut up by numerous islands, bays, and headlands, shoals and reefs, which makes the journey of all drift a long one, and adds greatly to the destruction of the bergs by stoppages and by causing them to break up. Disintegration is also hastened by their breaking away from the floe ice, for detached bergs will melt and break up rapidly even in high latitudes during the summer.

549. The Ice-Bearing Currents.—The Labrador Current passes to the southward along the coasts of Baffin Land and Labrador, and, although it occasionally ceases altogether, its usual rate is from 10 to 36 miles per day. Near the coast it is very much influenced by the winds, and reaches its maximum rate after those from

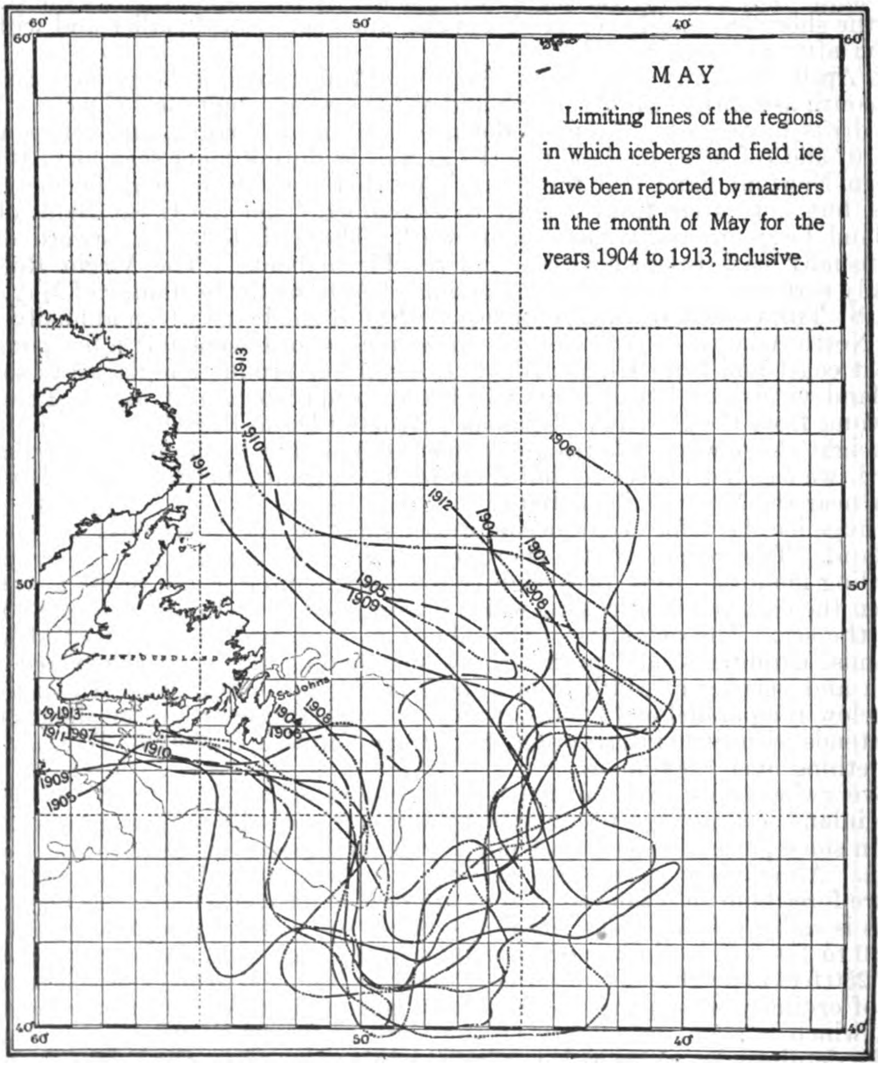


Fig. 79.

the northward. The general drift of the current is to the southward, as shown by the passage of many icebergs, although occasions have arisen on which these have been observed to travel northward without any apparent reason. The breadth and depth of the current are not known, but it is certain that it pours into the Atlantic enormous masses of water for which compensation is derived from the warm waters of the Atlantic and from the East Greenland Current that flows around Cape Farewell. The flow of the Polar Current down the east coast of Greenland has been abundantly demonstrated by the drift of vessels that have been beset in the ice pack to the eastward of Greenland. This current turns around Cape Farewell, with an ice stream

60 miles wide, and then takes a northwesterly direction along the Greenland coast as far as the Arctic Circle, where it meets the southerly current from Baffin Bay.

550. DRIFT AND CHARACTERISTICS OF ICEBERGS.—Not all the bergs made in any one season find their way south during the following one, for only a small percentage of them ever reach trans-Atlantic routes. So many delays attend their journey and so irregular and erratic is it that many bergs seen in any one season may have been made several seasons before. If bergs on their calving at once drifted to the southward and met with no obstructions their journey of about 1,200 to 1,500 miles would occupy from 4 to 5 months, reckoning the drift of the Labrador Current at 10 miles a day, which may be making it too little. Then, if bergs were liberated principally in July and August they should reach trans-Atlantic routes in December and January, while we know this to be the rare exception. It is then seen what an important bearing the shores of Labrador have in arresting their flow, when it is known that bergs are generally most plentiful in the late spring and early summer months off the Bank.

It should not be supposed that all bergs follow the same course when set adrift from their parent glaciers, for, like floating bodies at the head of a river, some will go direct to the mouth, others will go but a short distance and lodge, others still will accomplish half the journey and remain until another freshet again floats them, so that in the end the débris will be composed in part of that of several years' production.

Bergs, when first liberated on the west Greenland shore, are out of the strongest sweep of the southerly current, and they may take some months to find their way out of Davis Strait, while again others may at once drift into the current and move unobstructed until dissipated in the Gulf Stream. The difference in time of two bergs reaching a low latitude, which were set adrift the same day, may cover a period of one or two years.

Field ice also offers an obstruction to bergs, and a close season in the Arctic may prevent their liberation to a great extent, though, from their deep submersion, they act as ice plows and aid materially in breaking up the vast fields of ice which so often close the Arctic Basin.

Ice fields are more affected by wind than bergs. Bergs owe their drift almost entirely to current, so that they will often be noticed forcing their way through immense fields of heavy ice and going directly to windward. Advantage is taken of this by vessels in ice fields, which often moor to bergs and are towed for miles through ice in which they could not otherwise make any headway. This is accomplished by sinking an ice anchor into them and using a strong towline, and as the berg advances open water is left to leeward while the loose ice floats past on both sides. For the same reason vessels, when beset by field ice, run from the lee of one berg to that of another, as leads may offer themselves.

Instances are not rare where icebergs were seen to drift toward north, making 15 to 24 miles a day, near the tail of the Bank and to the eastward of Cape Race.

All ice is brittle, especially that in bergs, and it is wonderful how little it takes to accomplish their destruction. A blow of an ax will at times split them, and the report of a gun, by concussion, will accomplish the same end. They are more apt to break up in warm weather than cold, and whalers and sealers note this before landing on them, when an anchor is to be planted or fresh water to be obtained. On the coast of Labrador in July and August, when it is packed with bergs, the noise of rupture is often deafening, and those experienced in ice give them a wide berth.

When they are frozen the temperature is very low, so that when their surface is exposed to a thawing temperature the tension of the exterior and interior is very different, making them not unlike a Prince Rupert's drop. Then, too, during the day water made by melting finds its way into the crevices, freezes, and hence expands, and, acting like a wedge, forces the berg into fragments. It is the greatly increased surface which the fragments expose to the melting action of the oceanic waters that accounts for the rapid disappearance of the ice after it has reached the northern edge of the warm circulatory drift currents of the North Atlantic Ocean. If these processes of disintegration did not go on and large bergs should remain intact, several years might elapse before they would melt, and they would ever be present in the transoceanic routes. In fact, instances are on record in which masses of ice, escaping the influences of swift destruction or possessing a capability for resisting them, have, by phenomenal drifts, passed into European waters and been encountered from time to time throughout that portion of the ocean which stretches from the British Isles to the Azores.

Icebergs assume the greatest variety of shapes, from those approximating to some regular geometric figure to others crowned with spires, domes, minarets, and peaks, while others still are pierced by deep indentations or caves. Small cataracts fall from the large bergs, while from many icicles hang in clusters from every pro-

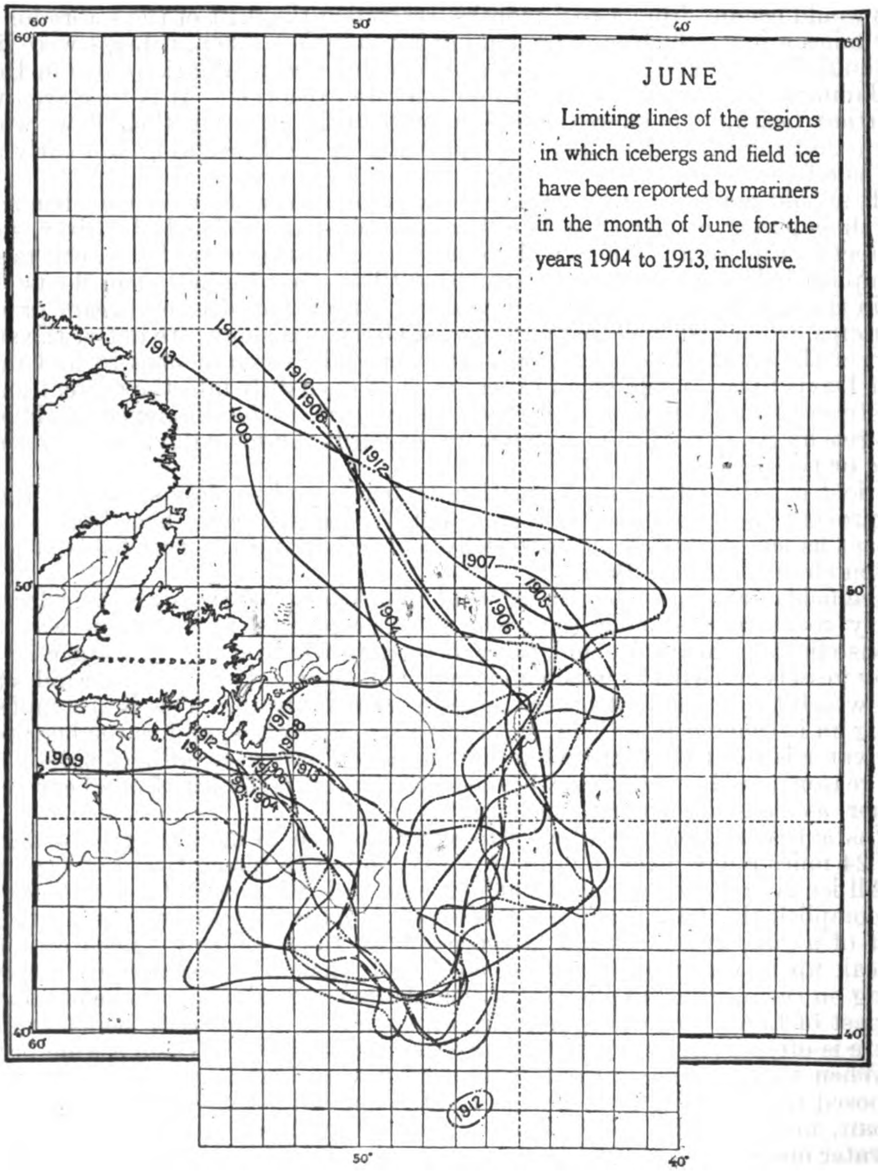


FIG 80.

jecting ledge. They frequently have outlying spurs under water, which are as dangerous as any other sunken reefs. For this reason it is advisable for vessels to give them a wide berth, for there are cases on record where vessels were seriously damaged by striking when apparently clear of the berg. Among these is that of the British steamship *Nessmore*, which ran into a berg in latitude 41° 50′ N., longitude 52° W., and stove in her bows. On docking her a long score was found extending from abreast her forerigging all of the way aft, just above her keel. Four frames were broken and the plates were almost cut through. The ship evidently struck a projecting spur after her helm had been put over, as there was clear water between her and the berg after the first collision.

It is generally best to go to windward of an iceberg, because the disintegrated fragments will have a tendency to drift to leeward while open water will be found to windward. Serious injury has occurred to vessels through the breaking up or capsizing of icebergs. Often the bergs are so nicely balanced that the slightest melting of their surfaces causes a shifting of the center of gravity and a consequent turning over of the mass into a new position, and this overturning also frequently takes place when bergs, drifting with the current in a state of delicate equilibrium, touch the ocean bottom.

551. Field Ice.—Field ice is formed throughout the region from the Arctic Ocean to the shores of Newfoundland and yearly leaves the shore to find its way into the path of commerce. Starting with the Arctic field ice and coming to the southward, we find this ice growing lighter, both in thickness and in quantity, until it disappears entirely. Ice made in the Arctic is heavier and has lived through a number of seasons. After the short summer in high latitudes ice begins to form on all open water, increasing several feet in thickness each season. Much of this remains north during the following summer, and, though it melts to some extent, it never entirely disappears, so that each succeeding winter adds to its thickness.

This continues from year to year until it reaches 12 or 15 feet in thickness, often more. If it remained perfectly quiet it would be of uniform thickness, increasing with the latitude, but it is in a state of almost continual motion, often a very violent one, which causes it to raft and pile until it becomes full of hummocks and other irregularities. Immense fields are detached from the shore and from other fields, and under the influence of winds, currents, and tides are set in motion and kept continually drifting from place to place; after a snow, thaw, or piling the whole becomes cemented together into solid pieces, when under the influence of a low temperature. The space of open water between the fields becomes frozen, joining smaller fields, and making a solid pack which will remain so until the elements again break it to pieces. Along the shores from headland to headland the bays and inlets often remain solid for years, almost invariably through the Arctic winter, but in Baffin Bay and Davis Strait open water can be found at intervals all the year round.

Ice becomes rafted in a variety of ways. If two fields are adrift the one to windward will drift down on the one to leeward; the one which is rougher on its surface gives the wind a better hold and drifts the faster; fields may be impelled towards each other by winds from contrary directions. Ice that is secure to the shore is rafted on its seaward edge from contact with that which is adrift. Fields in drifting often have a turning motion, which is caused by contrary currents, or one variable in strength at different places, or by the friction of a field coming in contact with another field afloat or one attached to the shore. This rotary motion is especially dangerous when a vessel finds itself between two fields. A heavy gale will break up the strongest fields at times and cause them to raft and form hummocks.

Small fragments of bergs find themselves mingled with Arctic fields and become frozen fast. These, when liberated to the southward, are called *growlers*, and form low, dark, indigo colored masses, which are just awash and rounded on top like a whale's back. They are very dangerous when in ice fields which have become loose enough to permit the passage of vessels through them, and should always be looked for; they can be seen apparently rising and sinking as the sea breaks over them.

During the spring and summer months the bergs, aided by a rise of temperature, so cut up and weaken the ice fields that much ice is loosened and begins drifting out of the Arctic basin. This is joined by that brought from the waters of Spitzbergen by the East Greenland Current, near the sixty-third parallel, whence it flows down the eastern coast of North America, reaching Cape Chidley about October or November. By this time the remaining ice in the Arctic is being cemented into solid fields, while the ice cap is being daily extended to the southward. As fast as fields are detached the open water freezes, and these masses are forced to the southward and can not rejoin the solid pack. With a westerly wind ice formed in Hudson Strait and adjacent waters is swept out and joins the Arctic ice, differing from it only in being a little lighter.

Ice begins to form at Cape Chidley about the middle of October, at Belle Isle about November 1, and by the middle of November or 1st of December, the whole coast is solidly frozen. The dates given are approximate and vary from year to year, with many marked exceptions.

The string of ice along the coast of Labrador extends from headland to headland, including the outlying islands, and starting from the heads of the bays works its way out to seaward, forming by the middle of December an impassable barrier to the shore which will probably not be permanently broken until the latter part of April. This ice varies in thickness from 12 feet at the northern extreme to 3 or 4 feet at the southern. During the entire winter the Arctic drift is finding its way down the coast, and is being continually reinforced by fields broken from the Labrador ice. These continue to the southward in the Labrador Current on an average of about 10 miles a day, reaching Belle Isle between the middle of January and the middle of February.

The best example on record of a continued drift from the Arctic is that of Captain Tyson. On October 14, 1871, he and a party of nineteen others were separated from the United States surveying ship *Polaris*, in latitude 77° or 78° N., just south of Littleton Island, and, being unable to regain the ship, remained on the floe and accomplished one of the most wonderful journeys. After a drift of over 1,500 miles, fraught with danger from beginning to end, they were picked up about six months later, April 30, 1872, by the *Tigress*, a sealing steamer from Newfoundland, near the Strait of Belleisle, in latitude 53° 35′ N., and carried safely into port.

Much delay in the southward movement of the drift will be caused by winds from the southward of west, as field ice is affected more by wind than current. The prevailing wind and weather will influence the drift very greatly. Strong northerly or northwest winds will increase its speed, but contrary winds will hold it back. The string of shore ice keeps the northern ice off the coast and in the current. At times westerly winds will also send the Labrador ice off the coast and leave it entirely clear, but this does not happen often. Still the outer Labrador ice is constantly being added to the Arctic flow. Frequently the bays remain frozen over until June; again, they are cleared some years in April, making a large variation. During the drift the wind from northwest to southwest will clear the ice off the coast and leave a line of open water, but the ice will be set on the coast by a northeast wind and be rafted and piled. The appearance of the ice when it reaches Belle Isle and to the southward would be a fair indication of the weather it had encountered on its way down. The rougher the ice the more severe the weather. This floating ice string extends approximately 200 miles offshore in the latitude of Cape Harrison, and spreads more during its drift, though narrower farther north. One small stream finds its way through the Strait of Belleisle, while the greater part continues toward the northern limit of the Gulf Stream. By the middle of January the shores of Newfoundland and Gulf of St. Lawrence are full of ice, which has been frozen there and are opened or closed by a favorable or adverse wind. Navigation in the River St. Lawrence is closed about the middle of November and does not open until about May. A wind from northwest to southwest will clear the eastern coast of Newfoundland, while the Gulf of St. Lawrence may remain full of ice until the 1st of May. Even after this date much ice is found in the Gulf until July, and by August or earlier the field ice is replaced in the Strait of Belleisle by bergs.

In the bight from Cape Bauld to Fogo Island a string of ice is often found joining these points, hemming in the shore for weeks at a time.

With each northwest or westerly wind the ice is cleared off the Newfoundland coast, except from some of the deeper bays, and carried out to sea, and frequently before the Arctic and Labrador ice has passed Belle Isle the Newfoundland ice has found its way as far south as latitude 45°. In the same way the Labrador ice sometimes precedes the Arctic ice, while all may arrive at nearly the same time. Ice fields often lose their identity, as coming from any one particular place, by the constant intermingling on its southern journey with ice made in a lower latitude.

With easterly winds the field ice and icebergs may block the harbors on the east coast of Newfoundland until June or even July, but these harbors are usually open in May.

Ice leaving the gulf and river St. Lawrence flows southward through Cabot Strait. This strait is never frozen over completely, but vessels not specially built to encounter ice can not navigate it safely between the beginning of January and the last of April on account of the heavy drift ice which blocks the passage. Nearly every spring, from about the middle of April to the middle of May, a great rush of ice out of the Gulf of St. Lawrence causes a block between St. Paul Island and Cape Ray. This block, which sometimes lasts for three or four weeks, and completely prevents the passage of ships, is known as the *bridge*. It is recorded that 300 vessels have at one time been detained by this obstacle.

The ice usually passes out of Cabot Strait in the direction of Banquereau Bank, with its eastern edge extending halfway between Scatari and St. Pierre Islands. Its path broadens after it is through the strait and is principally governed by the winds, but, under the influence of the current alone, it drifts southwestward, and in latitude 45° may be from 10 to 75 miles in width. Much of this ice is very heavy and prevents the passage through it of all vessels that are not specially built to encounter ice.

Ice fields assume a variety of shapes, depending upon the influence of winds and currents, and upon their shape on being set adrift. Those loosened in the Arctic meet with so many vicissitudes that they have entirely lost their original form when a low latitude is reached, while those from Newfoundland may remain approximately intact. Their extent is governed by the same rules and varies from a few scattered pieces to several hundred miles in length.

From off Belle Isle the field ice finds its way south toward the Gulf Stream, where no definite shape can be given it. In appearance, if heavy ice, it will be white, covered with snow, and visible at a long distance; even in foggy weather it can often be seen for some distance. It is full of hummocks and its surface is very uneven; blocks have been piled upon each other, others stood on end, and the whole mass will form an impenetrable field, through which vessels can not force their way.

If the ice is lighter the pans will be smoother and more even, the angles ground down by friction and turned up at the edges like so many large pond lilies. If compact, no water is seen; if loose, wide leads may extend through the whole, or a little water be seen surrounding each cake.

The appearance must decide whether a vessel is warranted in trying to force her way through. In a smooth sea, where doubt exists, should a vessel go dead slow into the mass, there will be but little danger in attempting it, and if too heavy she can haul out. Often the weather edge is the heaviest from being rafted, when to leeward it may be scattering. An ice field will often form a good lee for riding out a gale of wind, as it will break the force of the sea. But care is necessary not to lie too close, for the pans are often given such a force that they will stave in the bows of the strongest vessel.

A high temperature will soften field ice and make it very rotten, so that the slightest motion will cause it to fall to pieces. On reaching the waters of the Gulf Stream or a warmer atmospheric temperature it begins to melt, gets soft and spongy, and left in a calm will disappear slowly. But, fortunately, there is seldom a time when there is not a swell on the sea, and this soon breaks the pans into small pieces, thus bringing a greater surface in contact with the melting agency. A heavy gale will in a few hours sometimes cause the destruction of a large field by fracture, friction, and continued motion, just as a calm cold night may unite it in a solid mass. Bergs plow their way through fields, break them up, and scatter the pieces, as in the Arctic. Snow preserves them and often gives the pans the appearance of standing well out of water, and is misleading in this particular. By melting and afterwards freezing it adds to the thickness of the ice.

552. The Disappearance of the Ice.—The advancing ice will have reached, in the month of April, the northern average limit of the Gulf Stream; and, having spread itself along this line both east and west of the fiftieth meridian, it enters the final stage of disintegration and rapid disappearance.

After reaching this limit of southward movement, many bergs, on account of their deep immersion, find their way to the westward, even within the current of the Gulf Stream, while field ice never follows this course, a condition that is accounted for by the fact that the Labrador current here runs under the Gulf Stream, which spreads itself out on the surface as an eastward-moving current, consisting of streaks of warm water with colder water between.

The locality in which ice of all kinds is most apt to be found during the months of April, May, and June lies between latitude 42° and 45° and longitude 47° and 52° west of Greenwich. Here the Gulf Stream and the Labrador Current meet, and the movement of the ice is influenced sometimes by the one and sometimes by the other of these currents.

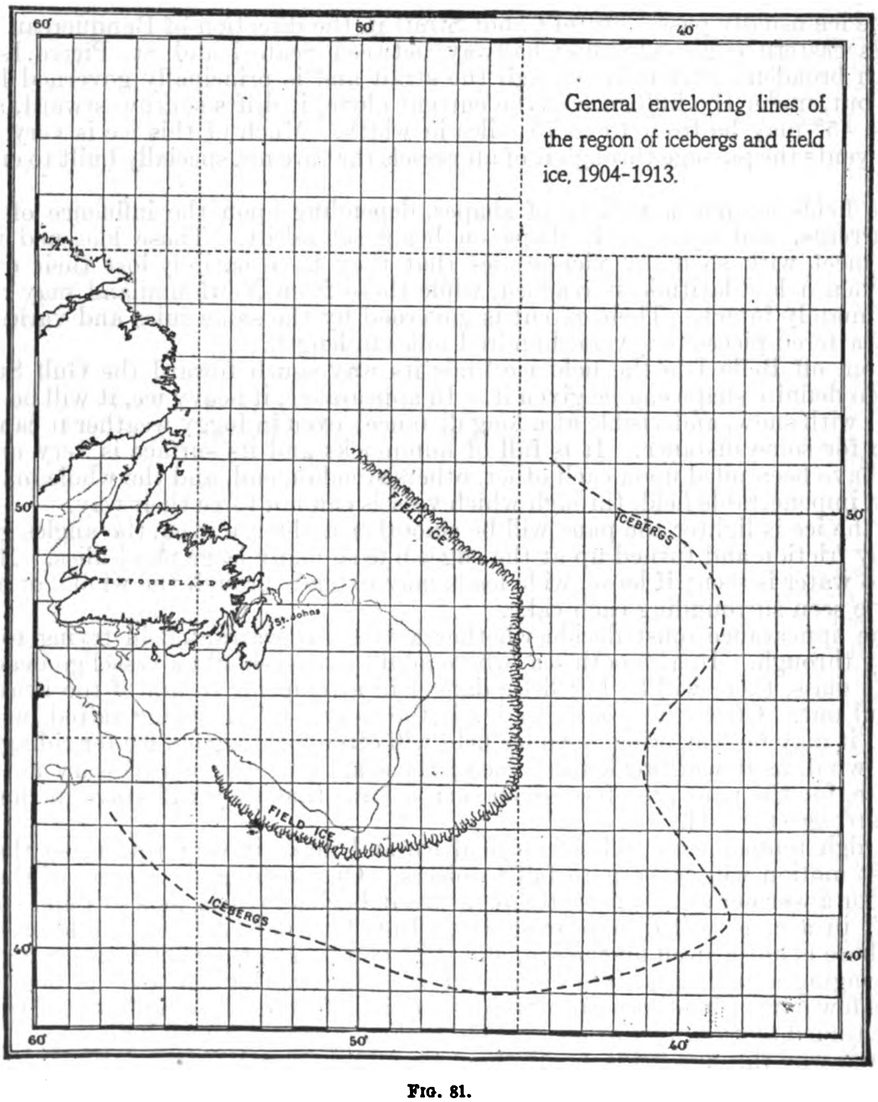


FIG. 81.

Besides the three charts of monthly limits for April, May, and June, a fourth chart is presented showing the general limits within which icebergs and field ice have been encountered during the same months.

553. Signs of the Proximity of Ice.—The proximity of ice is indicated by the following-described signs:

Before field ice is seen from deck the ice blink will often indicate its presence. On a clear day over an ice field on the horizon the sky will be much paler or lighter in color and is easily distinguished from that overhead, so that a sharp lookout should be kept and changes in the color of the sky noted.

On clear nights, especially when the moon is up, the sky along the horizon in the direction of the ice is markedly lighter than the rest of the horizon. This effect can be noted before the ice is sighted.

On a clear day icebergs can be seen at a long distance, owing to their brightness; during foggy weather they are first seen through the fog as a black object. In thick fog the first sight of a berg is apt to be a narrow streak of dark at the water line.

They can sometimes be detected by the echo from the steam whistle or the fog horn. In that case, by noting the time between the blast of a whistle and the reflected sound, the distance of the berg in feet may be approximately found by multiplying by 550. The absence of echo is by no means proof that no bergs are near, for unless there is a fairly vertical wall, no return of the sound waves can be expected.

The presence of icebergs is often made known by the noise of their breaking up and falling to pieces. The cracking of the ice or the falling of pieces into the sea makes a noise like breakers or a distant discharge of guns, which may often be heard a short distance.

The absence of swell or wave motion in a fresh breeze is a sign that there is land or ice on the weather side.

The appearance of herds of seal or flocks of murre far from land is an indication of the proximity of ice.

The special temperature studies made during the ice patrol of 1914 showed that no definite temperature effects of the air can be attributed to the presence of icebergs. Also that if there are temperature effects of sea water due to icebergs they are not distinguishable from the irregular variations observed.

In the ice zone ice is more likely to be found in cold water than in warm. So when encountering water below 40° in spring and below 50° in early summer, it is well to be on guard for ice. In foggy weather it is advisable to keep in water above 50° while crossing the ice zone, thereby avoiding both ice and fog.

A reliable sign of icebergs being near is the presence of calf ice. When such pieces occur in a curved line, as they may do, especially in calm weather, the parent berg is on the concave side of the curve.

No ship captain can afford to trust any of the above-named signs to the exclusion of a good lookout.

A remarkable optical phenomenon was observed one day by the ice patrol of 1914 when an iceberg which was ordinarily below the horizon was seen raised above it, at one time inverted and at another time erect. This phenomenon was observed near the Gulf Stream.

Current Information Regarding Ice Conditions.—The branch hydrographic offices receive daily the latest information regarding ice and other obstructions to navigation, being furnished with the reports of passing vessels and the ice-patrol ships, as long as such are in service. They also distribute the publications of the Hydrographic Office dealing with this topic, namely, the Hydrographic Bulletin (weekly) and the Pilot Chart (monthly), as well as the pamphlet on North Atlantic Ice Patrols (Reprint No. 24),

APPENDIX I.

EXTRACTS FROM THE AMERICAN NAUTICAL ALMANAC, FOR THE YEAR 1916, WHICH HAVE REFERENCE TO THE EXAMPLES FOR THAT YEAR GIVEN IN THIS WORK.

SUN, JANUARY, 1916.

G. M. T.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.
	° ′	m s	° ′	m s	° ′	m s
	Thursday 20.		Monday 24.		Friday 28.	
0	−20 20.8	−10 51.7	−19 27.4	−11 58.7	−18 28.2	−12 53.5
2	20 19.7	10 53.2	19 26.2	12 0.0	18 26.9	12 54.5
4	20 18.7	10 54.7	19 25.0	12 1.2	18 25.6	12 55.5
6	20 17.6	10 56.2	19 23.9	12 2.5	18 24.3	12 56.5
8	20 16.5	10 57.7	19 22.7	12 3.7	18 23.0	12 57.4
10	20 15.5	10 59.2	19 21.5	12 5.0	18 21.7	12 58.4
12	20 14.4	11 0.7	19 20.3	12 6.2	18 20.4	12 59.4
14	20 13.3	11 2.2	19 19.1	12 7.4	18 19.1	13 0.4
16	20 12.3	11 3.7	19 17.9	12 8.7	18 17.8	13 1.3
18	20 11.2	11 5.2	19 16.7	12 9.9	18 16.5	13 2.3
20	20 10.1	11 6.6	19 15.5	12 11.1	18 15.1	13 3.3
22	−20 9.1	−11 8.1	−19 14.3	−12 12.4	−18 13.8	−13 4.2
H. D.	0.5	0.7	0.6	0.6	0.7	0.5

SEMIDIAMETER.

	′
Jan. 1	16.30
11	16.30
21	16.28
31	16.26

SUN, APRIL, 1916.

G. M. T.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.
	° ′	m s	° ′	m s	° ′	m s	° ′	m s
	Sunday 2.		Sunday 16.		Friday 21.		Tuesday 25.	
0	+ 4 54.5	− 3 41.0	+10 6.3	+ 0 9.4	+11 50.5	+ 1 17.2	+13 10.4	+2 3.3
2	4 56.4	3 39.5	10 8.1	0 10.6	11 52.2	1 18.2	13 12.0	2 4.2
4	4 58.3	3 38.0	10 9.8	0 11.8	11 53.9	1 19.3	13 13.7	2 5.1
6	5 0.3	3 36.5	10 11.6	0 13.0	11 55.6	1 20.3	13 15.3	2 6.0
8	5 2.2	3 35.1	10 13.4	0 14.2	11 57.3	1 21.3	13 16.9	2 6.8
10	5 4.1	3 33.6	10 15.1	0 15.4	11 59.0	1 22.4	13 18.6	2 7.7
12	5 6.0	3 32.1	10 16.9	0 16.6	12 0.7	1 23.4	13 20.2	2 8.6
14	5 7.9	3 30.6	10 18.7	0 17.8	12 2.4	1 24.4	13 21.8	2 9.5
16	5 9.8	3 29.1	10 20.4	0 19.0	12 4.1	1 25.4	13 23.4	2 10.3
18	5 11.8	3 27.6	10 22.2	0 20.2	12 5.8	1 26.4	13 25.1	2 11.2
20	5 13.7	3 26.2	10 24.0	0 21.4	12 7.4	1 27.4	13 26.7	2 12.0
22	5 15.6	3 24.7	+10 25.7	+ 0 22.6	12 9.1	1 28.4	13 28.3	2 12.9
H. D.	1.0	0.7	0.9	0.6	0.8	0.5	0.8	0.4
	Thursday 13.		Monday 17.		Saturday 22.		Wednesday 26.	
0	+ 9 1.7	− 0 35.6	+10 27.5	+ 0 23.8	+12 10.8	+ 1 29.4	+13 29.9	+2 13.7
2	9 3.5	0 34.3	10 29.3	0 25.0	12 12.5	1 30.4	13 31.5	2 14.5
4	9 5.3	0 33.0	10 31.0	0 26.1	12 14.2	1 31.4	13 33.1	2 15.4
6	9 7.2	0 31.7	10 32.8	0 27.3	12 15.9	1 32.4	13 34.7	2 16.2
8	9 9.0	0 30.5	10 34.5	0 28.5	12 17.5	1 33.4	13 36.3	2 17.0
10	9 10.8	0 29.2	10 36.3	0 29.6	12 19.2	1 34.4	13 37.9	2 17.9
12	9 12.6	0 27.9	10 38.0	0 30.8	12 20.9	1 35.4	13 39.5	2 18.7
14	9 14.4	0 26.6	10 39.8	0 32.0	12 22.6	1 36.4	13 41.1	2 19.5
16	9 16.2	0 25.4	10 41.5	0 33.1	12 24.2	1 37.3	13 42.7	2 20.3
18	9 18.0	0 24.1	10 43.3	0 34.3	12 25.9	1 38.3	13 44.3	2 21.1
20	9 19.8	0 22.8	10 45.0	0 35.4	12 27.6	1 39.3	13 45.9	2 21.9
22	9 21.6	0 21.6	10 46.8	0 36.6	12 29.2	1 40.2	13 47.5	2 22.7
H. D.	0.9	0.6	0.9	0.6	0.8	0.5	0.8	0.4

NOTE.—The Equation of Time is to be applied to the G. M. T. in accordance with the sign as given.

G. M. T.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.
	° ′	m s	° ′	m s	° ′	m s	° ′	m s
	SUN, APRIL, 1916.							
	Saturday 15.		Wednesday 19.		Sunday 23.		SEMIDIAMETER.	
0	+9 44.9	+0 5.2	+11 9.4	+0 51.3	+12 30.9	+1 41.2		
2	9 46.7	0 4.0	11 11.1	0 52.4	12 32.6	1 42.2		
4	9 48.5	0 2.8	11 12.8	0 53.5	12 34.2	1 43.1		
6	9 50.3	0 1.5	11 14.6	0 54.6	12 35.9	1 44.1		
8	9 52.0	−0 0.3	11 16.3	0 55.7	12 37.5	1 45.0	Apr. 1	16.03
10	9 53.8	+0 0.9	11 18.0	0 56.8	12 39.2	1 46.0	11	15.98
12	9 55.6	0 2.1	11 19.7	0 57.9	12 40.8	1 46.9	21	15.94
14	9 57.4	0 3.3	11 21.4	0 59.0	12 42.5	1 47.8	May 1	15.90
16	9 59.2	0 4.5	11 23.1	1 0.1	12 44.1	1 48.8		
18	10 1.0	0 5.8	11 24.9	1 1.2	12 45.8	1 49.7		
20	10 2.7	0 7.0	11 26.6	1 2.2	12 47.4	1 50.6		
22	10 4.5	0 8.2	11 28.3	1 3.3	12 49.1	1 51.6		
H. D.	0.9	0.6	0.9	0.5	0.8	0.5		
	SUN, MAY, 1916.							
	Sunday 14.		Monday 15.		Wednesday 17.		Sunday 21.	
0	+18 37.0	+3 47.5	+18 51.4	+3 47.5	+19 19.1	+3 45.7	+20 10.6	+3 35.6
2	18 38.2	3 47.5	18 52.5	3 47.4	19 20.2	3 45.6	20 11.6	3 35.2
4	18 39.4	3 47.5	18 53.7	3 47.4	19 21.3	3 45.5		
6	18 40.6	3 47.5	18 54.9	3 47.3	19 22.4	3 45.3		
8	18 41.8	3 47.5	18 56.1	3 47.3	19 23.6	3 45.2		
10	18 43.0	3 47.5	18 57.2	3 47.2	19 24.7	3 45.0	SEMIDIAMETER.	
12	18 44.2	3 47.5	18 58.4	3 47.2	19 25.8	3 44.9		
14	18 45.4	3 47.5	18 59.6	3 47.1	19 26.9	3 44.8		
16	18 46.6	3 47.5	19 0.7	3 47.1	19 28.0	3 44.6	May 1	15.90
18	18 47.8	3 47.5	19 1.9	3 47.0	19 29.1	3 44.5	11	15.86
20	18 49.0	3 47.5	19 3.1	3 47.0	19 30.3	3 44.3	21	15.83
22	18 50.2	3 47.5	19 4.2	3 46.9	19 31.4	3 44.2	31	15.80
H. D.	0.6	0.0	0.6	0.0	0.6	0.1		
	SUN, JUNE, 1916.							
	Wednesday 7.		Tuesday 13.		Wednesday 21.		Sunday 25.	
0	+22 45.2	+1 23.2	+23 13.0	+0 12.5	+23 27.1	−1 29.6	+23 24.2	−2 21.2
2	22 45.7	1 22.3	23 13.2	0 11.5	23 27.1	1 30.6	23 24.1	2 22.3
4	22 46.2	1 21.3	23 13.5	0 10.5	23 27.1	1 31.7	23 23.9	2 23.4
6	22 46.6	1 20.4	23 13.8	0 9.4	23 27.1	1 32.8	23 23.8	2 24.4
8	22 47.1	1 19.4	23 14.0	0 8.4	23 27.1	1 33.9	23 23.6	2 25.5
10	22 47.6	1 18.5	23 14.3	0 7.4	23 27.1	1 35.0	23 23.5	2 26.5
12	22 48.0	1 17.6	23 14.6	0 6.4	23 27.1	1 36.0	23 23.3	2 27.6
14	22 48.5	1 16.6	23 14.8	0 5.3	23 27.1	1 37.1	23 23.2	2 28.6
16	22 49.0	1 15.7	23 15.1	0 4.3	23 27.1	1 38.2	23 23.0	2 29.7
18	22 49.4	1 14.7	23 15.4	0 3.3	23 27.1	1 39.3	23 22.9	2 30.8
20	22 49.9	1. 13 8	23 15.6	0 2.2	23.27 0	1 40.4	23 22.8	2 31.8
22	22 50.4	1 12.9	23 15.9	0 1.2	23 27.0	1. 41.4	23 22.6	2 32.9
H. D.	0.2	0.5	0.1	0.5	0.0	0.5	0.1	0.5
	Monday 19.		Friday 23.		Tuesday 27.			
0	+23 26.0	−1 3.6	+23 26.5	−1 55.5	+23 20.3	−2 46.6		
2	23 26.1	1 4.7	23 26.4	1 56.6	23 20.1	2 47.6		
4	23 26.1	1 5.8	23 26.3	1 57.6	23 19.9	2 48.6	SEMIDIAMETER.	
6	23 26.2	1 6.9	23 26.2	1 58.7	23 19.7	2 49.7		
8	23 26.3	1 8.0	23 26.2	1 59.8	23 19.4	2 50.7	June 1	15.80
10	23 26.3	1 9.0	23 26.1	2 0.8	23 19.2	2 51.8	11	15.78
12	23 26.4	1 10.1	23 26.0	2 1.9	23 19.0	2 52.8	21	15.77
14	23 26.4	1 11.2	23 25.9	2 3.0	23 18.8	2 53.8	July 1	15.76

NOTE.—The Equation of Time is to be applied to the G. M. T. in accordance with the sign as given.

G. M. T.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.	Sun's Declination.	Equation of Time.
h	° ′	m s	° ′	m s	° ′	m s	° ′	m s
			SUN, JULY, 1916.					
	Wednesday 12.		Monday 24.		Friday 28.			
0	+21 59.6	−5 23.5	+19 53.9	−6 18.1	+19 0.9	−6 18.8		
2	21 58.9	5 24.1	19 52.8	6 18.2	18 59.8	6 18.7		
4	21 58.2	5 24.7	19 51.7	6 18.3	18 58.6	6 18.6		
6	21 57.5	5 25.3	19 50.7	6 18.4	18 57.4	6 18.5	SEMIDIAMETER.	
8	21 56.8	5 25.9	19 49.6	6 18.5	18 56.3	6 18.4		′
10	21 56.1	5 26.5	19 48.6	6 18.5	18 55.1	6 18.3		
12	21 55.4	5 27.1	19 47.5	6 18.6	18 53.9	6 18.2	July 1	15.76
14	21 54.7	5 27.8	19 46.4	6 18.7	18 52.8	6 18.1	11	15.76
							21	15.77
16	21 54.0	5 28.4	19 45.4	6 18.8	18 51.6	6 18.0	31	15.79
18	21 53.3	5 29.0	19 44.3	6 18.9	18 50.4	6 17.9		
20	21 52.6	5 29.6	19 43.2	6 19.0	18 49.2	6 17.8		
22	+21 51.9	−5 30.2	+19 42.2	−6 19.1	+18 48.1	−6 17.6		
H. D.	0.4	0.3	0.5	0.0	0.6	0.1		
			SUN, OCTOBER, 1916.					
	Sunday 1.		Thursday 5.		Monday 9.		Friday 13.	
0	−3 9.8	+10 16.1	−4 42.7	+11 30.4	−6 14.6	+12 39.1	−7 45.2	+13 40.8
2	3 11.7	10 17.7	4 44.6	11 31.9	6 16.5	12 40.5		
4	3 13.7	10 19.3	4 46.5	11 33.4	6 18.4	12 41.9		
6	3 15.6	10 20.9	4 48.4	11 34.9	6 20.3	12 43.2		
8	3 17.5	10 22.5	4 50.4	11 36.4	6 22.2	12 44.6	SEMIDIAMETER.	
10	3 19.5	10 24.0	4 52.3	11 37.9	6 24.1	12 45.9		
12	3 21.4	10 25.6	4 54.2	11 39.3	6 26.0	12 47.3		
14	3 23.4	10 27.2	4 56.1	11 40.8	6 27.9	12 48.6		′
							Oct. 1	16.01
16	3 25.3	10 28.8	4 58.1	11 42.3	6 29.8	12 49.9	11	16.06
18	3 27.2	10 30.4	5 0.0	11 43.8	6 31.7	12 51.3	21	16.10
20	3 29.2	10 32.0	5 1.9	11 45.2	6 33.6	12 52.6	31	16.15
22	3 31.1	10 33.5	5 3.8	11 46.7	6 35.5	12 53.9		
H. D.	1.0	0.8	1.0	0.7	0.9	0.7		

NOTE.—The Equation of Time is to be applied to the G. M. T. in accordance with the sign as given.

SUN, 1916.

Day of Month.	Right Ascension of the Mean Sun at Greenwich Mean Noon.					
	January.	February.	March.	April.	May.	June.
	h m s	h m s	h m s	h m s	h m s	h m s
1	18 39 16.2	20 41 29.5	22 35 49.6	0 38 2.7	2 36 19.4	4 38 32.6
2	18 43 12.8	20 45 26.0	22 39 46.1	0 41 59.3	2 40 15.9	4 42 29.2
3	18 47 9.3	20 49 22.6	22 43 42.7	0 45 55.8	2 44 12.5	4 46 25.7
4	18 51 5.9	20 53 19.2	22 47 39.2	0 49 52.4	2 48 9.0	4 50 22.3
5	18 55 2.4	20 57 15.7	22 51 35.8	0 53 49.0	2 52 5.6	4 54 18.8
6	18 58 59.0	21 1 12.3	22 55 32.3	0 57 45.5	2 56 2.1	4 58 15.4
7	19 2 55.5	21 5 8.8	22 59 28.9	1 1 42.0	2 59 58.7	5 2 12.0
8	19 6 52.1	21 9 5.4	23 3 25.4	1 5 38.6	3 3 55.2	5 6 8.5
9	19 10 48.7	21 13 1.9	23 7 22.0	1 9 35.2	3 7 51.8	5 10 5.1
10	19 14 45.2	21 16 58.5	23 11 18.6	1 13 31.7	3 11 48.4	5 14 1.6
11	19 18 41.8	21 20 55.0	23 15 15.1	1 17 28.3	3 15 44.9	5 17 58.2
12	19 22 38.3	21 24 51.6	23 19 11.7	1 21 24.8	3 19 41.5	5 21 54.8
13	19 26 34.9	21 28 48.2	23 23 8.2	1 25 21.4	3 23 38.0	5 25 51.3
14	19 30 31.4	21 32 44.7	23 27 4.8	1 29 17.9	3 27 34.6	5 29 47.9
15	19 34 28.0	21 36 41.3	23 31 1.3	1 33 14.5	3 31 31.2	5 33 44.4
16	19 38 24.6	21 40 37.8	23 34 57.9	1 37 11.0	3 35 27.7	5 37 41.0
17	19 42 21.1	21 44 34.4	23 38 54.4	1 41 7.6	3 39 24.3	5 41 37.6
18	19 46 17.7	21 48 30.9	23 42 51.0	1 45 4.2	3 43 20.8	5 45 34.1
19	19 50 14.2	21 52 27.5	23 46 47.5	1 49 0.7	3 47 17.4	5 49 30.7
20	19 54 10.8	21 56 24.0	23 50 44.1	1 52 57.3	3 51 13.9	5 53 27.2
21	19 58 7.4	22 0 20.6	23 54 40.6	1 56 53.8	3 55 10.5	5 57 23.8
22	20 2 3.9	22 4 17.1	23 58 37.2	2 0 50.4	3 59 7.0	6 1 20.3
23	20 6 0.5	22 8 13.7	0 2 33.8	2 4 46.9	4 3 3.6	6 5 16.9
24	20 9 57.0	22 12 10.2	0 6 30.3	2 8 43.5	4 7 0.2	6 9 13.5
25	20 13 53.6	22 16 6.8	0 10 26.9	2 12 40.0	4 10 56.7	6 13 10.0
26	20 17 50.1	22 20 3.4	0 14 23.4	2 16 36.6	4 14 53.3	6 17 6.6
27	20 21 46.7	22 23 59.9	0 18 20.0	2 20 33.1	4 18 49.8	6 21 3.1
28	20 25 43.2	22 27 56.5	0 22 16.5	2 24 29.7	4 22 46.4	6 24 59.7
29	20 29 39.8	22 31 53.0	0 26 13.1	2 28 26.2	4 26 43.0	6 28 56.2
30	20 33 36.4	22 35 49.6	0 30 9.6	2 32 22.8	4 30 39.5	6 32 52.8
31	20 37 32.9	22 39 46.1	0 34 6.2	2 36 19.4	4 34 36.1	6 36 49.4

CORRECTION TO BE ADDED TO R. A. M. S. AT G. M. N. FOR TIME PAST NOON.

Time.	0m	6m	12m	18m	24m	30m	36m	42m	48m	54m	60m	Time.
h	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	h
0	0 0.0	0 1.0	0 2.0	0 3.0	0 3.9	0 4.9	0 5.9	0 6.9	0 7.9	0 8.9	0 9.9	0
1	0 9.9	0 10.8	0 11.8	0 12.8	0 13.8	0 14.8	0 15.8	0 16.8	0 17.7	0 18.7	0 19.7	1
2	0 19.7	0 20.7	0 21.7	0 22.7	0 23.7	0 24.6	0 25.6	0 26.6	0 27.6	0 28.6	0 29.6	2
3	0 29.6	0 30.6	0 31.5	0 32.5	0 33.5	0 34.5	0 35.5	0 36.5	0 37.5	0 38.4	0 39.4	3
4	0 39.4	0 40.4	0 41.4	0 42.4	0 43.4	0 44.4	0 45.3	0 46.3	0 47.3	0 48.3	0 49.3	4
5	0 49.3	0 50.3	0 51.3	0 52.2	0 53.2	0 54.2	0 55.2	0 56.2	0 57.2	0 58.2	0 59.1	5
6	0 59.1	1 0.1	1 1.1	1 2.1	1 3.1	1 4.1	1 5.1	1 6.0	1 7.0	1 8.0	1 9.0	6
7	1 9.0	1 10.0	1 11.0	1 12.0	1 12.9	1 13.9	1 14.9	1 15.9	1 16.9	1 17.9	1 18.9	7
8	1 18.9	1 19.8	1 20.8	1 21.8	1 22.8	1 23.8	1 24.8	1 25.7	1 26.7	1 27.7	1 28.7	8
9	1 28.7	1 29.7	1 30.7	1 31.7	1 32.7	1 33.6	1 34.6	1 35.6	1 36.6	1 37.6	1 38.6	9
10	1 38.6	1 39.6	1 40.5	1 41.5	1 42.5	1 43.5	1 44.5	1 45.5	1 46.5	1 47.4	1 48.4	10
11	1 48.4	1 49.4	1 50.4	1 51.4	1 52.4	1 53.3	1 54.3	1 55.3	1 56.3	1 57.3	1 58.3	11

SUN, 1916.

Day of Month.	Right Ascension of the Mean Sun at Greenwich Mean Noon.					
	July.	August.	September.	October.	November.	December.
	h m s	h m s	h m s	h m s	h m s	h m s
1	6 36 49.4	8 39 2.6	10 41 15.8	12 39 32.4	14 41 45.6	16 40 2.3
2	6 40 45.9	8 42 59.2	10 45 12.4	12 43 29.0	14 45 42.2	16 43 58.9
3	6 44 42.5	8 46 55.8	10 49 9.0	12 47 25.6	14 49 38.7	16 47 55.4
4	6 48 39.0	8 50 52.3	10 53 5.5	12 51 22.1	14 53 35.3	16 51 52.0
5	6 52 35.6	8 54 48.9	10 57 2.1	12 55 18.7	14 57 31.8	16 55 48.6
6	6 56 32.2	8 58 45.4	11 0 58.6	12 59 15.2	15 1 28.4	16 59 45.1
7	7 0 28.7	9 2 42.0	11 4 55.2	13 3 11.8	15 5 25.0	17 3 41.7
8	7 4 25.3	9 6 38.5	11 8 51.7	13 7 8.3	15 9 21.5	17 7 38.2
9	7 8 21.8	9 10 35.1	11 12 48.3	13 11 4.9	15 13 18.1	17 11 34.8
10	7 12 18.4	9 14 31.6	11 16 44.8	13 15 1.4	15 17 14.6	17 15 31.4
11	7 16 14.9	9 18 28.2	11 20 41.4	13 18 58.0	15 21 11.2	17 19 27.9
12	7 20 11.5	9 22 24.8	11 24 37.9	13 22 54.5	15 25 7.7	17 23 24.5
13	7 24 8.1	9 26 21.3	11 28 34.5	13 26 51.1	15 29 4.3	17 27 21.0
14	7 28 4.6	9 30 17.9	11 32 31.0	13 30 47.6	15 33 0.8	17 31 17.6
15	7 32 1.2	9 34 14.4	11 36 27.6	13 34 44.2	15 36 57.4	17 35 14.1
16	7 35 57.7	9 38 11.0	11 40 24.2	13 38 40.8	15 40 54.0	17 39 10.7
17	7 39 54.3	9 42 7.5	11 44 20.7	13 42 37.3	15 44 50.5	17 43 7.3
18	7 43 50.8	9 46 4.1	11 48 17.3	13 46 33.9	15 48 47.1	17 47 3.8
19	7 47 47.4	9 50 0.6	11 52 13.8	13 50 30.4	15 52 43.6	17 51 0.4
20	7 51 44.0	9 53 57.2	11 56 10.4	13 54 27.0	15 56 40.2	17 54 56.9
21	7 55 40.5	9 57 53.8	12 0 6.9	13 58 23.5	16 0 36.8	17 58 53.5
22	7 59 37.1	10 1 50.3	12 4 3.5	14 2 20.1	16 4 33.3	18 2 50.0
23	8 3 33.6	10 5 46.9	12 8 0.0	14 6 16.6	16 8 29.9	18 6 46.6
24	8 7 30.2	10 9 43.4	12 11 56.6	14 10 13.2	16 12 26.4	18 10 43.2
25	8 11 26.8	10 13 40.0	12 15 53.1	14 14 9.7	16 16 23.0	18 14 39.7
26	8 15 23.3	10 17 36.5	12 19 49.7	14 18 6.3	16 20 19.5	18 18 36.3
27	8 19 19.9	10 21 33.1	12 23 46.2	14 22 2.8	16 24 16.1	18 22 32.8
28	8 23 16.4	10 25 29.6	12 27 42.8	14 25 59.4	16 28 12.6	18 26 29.4
29	8 27 13.0	10 29 26.2	12 31 39.3	14 29 56.0	16 32 9.2	18 30 26.0
30	8 31 9.5	10 33 22.7	12 35 35.9	14 33 52.5	16 36 5.8	18 34 22.5
31	8 35 6.1	10 37 19.3	12 39 32.4	14 37 49.1	16 40 2.3	18 38 19.1

CORRECTION TO BE ADDED TO R. A. M. S. AT G. M. N. FOR TIME PAST NOON.

Time.	0m	6m	12m	18m	24m	30m	36m	42m	48m	54m	60m	Time.
h	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	h
12	1 58.3	1 59.3	2 0.2	2 1.2	2 2.2	2 3.2	2 4.2	2 5.2	2 6.2	2 7.1	2 8.1	12
13	2 8.1	2 9.1	2 10.1	2 11.1	2 12.1	2 13.1	2 14.0	2 15.0	2 16.0	2 17.0	2 18.0	13
14	2 18.0	2 19.0	2 20.0	2 20.9	2 21.9	2 22.9	2 23.9	2 24.9	2 25.9	2 26.9	2 27.8	14
15	2 27.8	2 28.8	2 29.8	2 30.8	2 31.8	2 32.8	2 33.8	2 34.7	2 35.7	2 36.7	2 37.7	15
16	2 37.7	2 38.7	2 39.7	2 40.7	2 41.6	2 42.6	2 43.6	2 44.6	2 45.6	2 46.6	2 47.6	16
17	2 47.6	2 48.5	2 49.5	2 50.5	2 51.5	2 52.5	2 53.5	2 54.5	2 55.4	2 56.4	2 57.4	17
18	2 57.4	2 58.4	2 59.4	3 0.4	3 11.4	3 2.3	3 3.3	3 4.3	3 5.3	3 6.3	3 7.3	18
19	3 7.3	3 8.3	3 9.2	3 10.2	3 11.2	3 12.2	3 13.2	3 14.2	3 15.2	3 16.1	3 17.1	19
20	3 17.1	3 18.1	3 19.1	3 20.1	3 21.1	3 22.1	3 23.0	3 24.0	3 25.0	3 26.0	3 27.0	20
21	3 27.0	3 28.0	3 29.0	3 29.9	3 30.9	3 31.9	3 32.9	3 33.9	3 34.9	3 35.9	3 36.8	21
22	3 36.8	3 37.8	3 38.8	3 39.8	3 40.8	3 41.8	3 42.8	3 43.7	3 44.7	3 45.7	3 46.7	22
23	3 46.7	3 47.7	3 48.7	3 49.7	3 50.6	3 51.6	3 52.6	3 53.6	3 54.6	3 55.6	3 56.6	23

MOON, 1916.

April 15.

G. M. T.	Right Ascension.		Declination.		S. D.	H. P.
h	h m s		° ′		′	′
0	11 20 23	235	+ 0 19.2	294	15.5	56.9
2	11 24 18	236	− 0 10.2	296	15.6	57.0
4	11 28 14	236	0 39.8	295	15.6	57.1
6	11 32 10	237	1 9.3	296	15.6	57.1
8	11 36 7	238	1 38.9	297	15.6	57.2
10	11 40 5	238	2 8.6	297	15.6	57.3
12	11 44 3	239	2 38.3	297	15.6	57.3
14	11 48 2	240	3 8.0	297	15.7	57.4
16	11 52 2	241	3 37.7	298	15.7	57.5
18	11 56 3	242	4 7.5	297	15.7	57.5
20	12 0 5	242	4 37.2	297	15.7	57.6
22	12 4 7	243	5 6.9	296	15.7	57.6

May 6.

G. M. T.	Right Ascension.		Declination.		S. D.	H. P.
h	h m s		° ′		′	′
0	6 15 36	262	+25 48.6	64	14.8	54.2
2	6 19 58	261	25 42.2	70	14.8	54.2
4	6 24 19	261	25 35.2	74	14.8	54.2
6	6 28 40	260	25 27.8	78	14.8	54.2
8	6 33 0	259	25 20.0	84	14.8	54.2
10	6 37 19	259	25 11.6	88	14.8	54.1
12	6 41 38	258	25 2.8	93	14.8	54.1
14	6 45 56	257	24 53.5	97	14.8	54.1
16	6 50 13	257	24 43.8	102	14.8	54.1
18	6 54 30	255	24 33.6	107	14.8	54.1
20	6 58 45	255	24 22.9	111	14.8	54.1
22	7 3 0	254	24 11.8	115	14.8	54.1

July 10.

G. M. T.	Right Ascension.		Declination.		S. D.	H. P.
0	14 35 34	285	−20 37.9	199	16.0	58.7
2	14 40 19	287	20 57.8	194	16.0	58.8
4	14 45 6	289	21 17.2	190	16.1	58.9
6	14 49 55	291	21 36.2	186	16.1	58.9
8	14 54 46	293	21 54.8	180	16.1	59.0
10	14 59 39	296	22 12.8	176	16.1	59.1
12	15 4 35	297	22 30.4	170	16.1	59.2
14	15 9 32	299	22 47.4	165	16.2	59.2
16	15 14 31	302	23 3.9	159	16.2	59.3
18	15 19 33	303	23 19.8	154	16.2	59.4
20	15 24 36	305	23 35.2	148	16.2	59.5
22	15 29 41	307	23 50.0	142	16.2	59.5
24	15 34 48		−24 4.2		16.3	59.6

October 10.

G. M. T.	Right Ascension.		Declination.		S. D.	H. P.
0	0 16 45	255	+ 6 59.3	294	16.0	58.6
2	0 21 0	255	7 28.7	293	16.0	58.5
4	0 25 15	255	7 58.0	291	16.0	58.5
6	0 29 30	255	8 27.1	288	16.0	58.5
8	0 33 45	256	8 55.9	286	15.9	58.4
10	0 38 1	255	9 24.5	284	15.9	58.4
12	0 42 16	257	9 52.9	281	15.9	58.3
14	0 46 33	256	10 21 0	279	15.9	58.3
16	0 50 49	257	10 48.9	276	15.9	58.2
18	0 55 6	257	11 16.5	273	15.9	58.2
20	0 59 23	258	11 43.8	270	15.9	58.1
22	1 3 41	258	12 10.8	268	15.9	58.1
24	1 7 59		+12 37.6		15.8	58.0

TIME OF TRANSIT, MERIDIAN OF GREENWICH.

Date	h m		Date	h m		Date	h m		Date	h m	
Feb. 16	10 37	46	May 20	15 29	59	June 18	15 12	53	July 10	7 40	60
17	11 23		21	16 28	53	19	16 5	48	11	8 40	
Apr. 14	9 21	44	22	17 21	49	20	16 53	47	18	15 33	47
15	10 5		23	18 10		21	17 40	45	19	16 20	

JUPITER, 1916.

Greenwich Mean Time.

Date.	Apparent Right Ascension. Noon.		Apparent Declination. Noon.		Transit, Meridian of Greenwich.	Date.	Apparent Right Ascension. Noon.		Apparent Declination. Noon.		Transit, Meridian of Greenwich.
	h m s		° ′		h m		h m s		° ′		h m
Apr. 15	0 56 28	54	+ 4 51.5	55	23 20	Sept. 15	2 11 38	16	+11 41.1	16	14 33
16	0 57 22	53	4 57.0	56	23 17	16	2 11 22	17	11 39.5	16	14 28
July 25	2 8 20	22	+11 35.9	17	17 54	17	2 11 5	17	11 37.9	17	14 24
26	2 8 42	22	+11 37.6	16	17 51	18	2 10 48	18	11 36.2	17	14 20

Polar Semidiameter: July 1, 0′.30; Aug. 1, 0′.33; Sept. 1, 0′.36; Oct. 1, 0′.39; Nov. 1, 0′.39; Dec. 1, 0′.37; Dec. 32, 0′.34.
Hor. Parallax: Apr. 1, 0′.02; May 1, 0′.02; July 1, 0′.03; Aug. 1, 0′.03; Sept. 1, 0′.03; Oct. 1, 0′.04; Nov. 1, 0′.04; Dec. 1, 0′.04; Dec. 32, 0′.03.

VENUS, 1916.

Greenwich Mean Time.

Date	RA		Dec		Transit	Date	RA		Dec		Transit
Apr 16	4 38 4	267	+25 14.7	110	3 1	June 1	7 17 48	90	+24 48.5	93	2 39

Semidiameter: Jan. 1, 0′.10; Feb. 1, 0′.11; Mar. 1, 0′.13; Apr. 1, 0′.16; May 1, 0′.22; June 1, 0′.34; July 1, 0′.49.
Hor. Parallax: Jan. 1, 0′.10; Feb. 1, 0′.11; Mar. 1, 0′.13; Apr. 1, 0′.16; May 1, 0′.22; June 1, 0′.35; July 1, 0′.50.

APPARENT PLACES OF STARS, 1916.

FOR THE UPPER TRANSIT AT GREENWICH.

Right Ascension.

No.	Constellation Name.	h m	Jan. 1.	Feb. 1.	Mar. 1.	Apr. 1.	May 1.	June 1.	July 1.	Aug. 1.	Sept. 1.	Oct. 1.	Nov. 1.	Dec. 1.	Dec. 32.
		h m	s	s	s	s	s	s	s	s	s	s	s	s	s
1	α Androm.	0 4	3.0	2.6	2.4	2.5	3.1	4.0	5.1	6.1	6.7	7.0	7.0	6.7	6.3
2	β Cassiop.	0 4	41.1	40.2	39.9	39.8	40.7	42.1	43.7	45.1	46.1	46.5	46.3	45.7	44.8
3	β Ceti	0 39	23.4	23.0	22.8	22.8	23.2	23.9	24.9	25.9	26.6	27.0	27.0	26.8	26.5
4	δ Cassiop.	1 20	19.5	18.5	17.8	17.4	17.9	19.1	20.7	22.3	23.6	24.6	24.9	24.6	23.9
5	α Urs. Min.	1 28	111.0	79.0	52.7	38.6	44.5	67.5	99.0	133.4	163.2	182.2	186.8	175.0	149.0
6	α Eridani	1 34	37.0	35.9	35.2	34.7	34.7	35.6	36.8	38.2	39.5	40.3	40.4	40.0	39.1
7	α Arietis	2 2	27.4	27.0	26.6	26.3	26.5	27.2	28.1	29.1	30.1	30.7	31.1	31.2	31.0
8	θ Eridani	2 55	6.5	5.9	5.3	4.7	4.5	4.9	5.7	6.7	7.8	8.6	9.1	9.1	8.8
9	α Persei	3 18	21.3	20.8	20.1	19.5	19.3	19.9	21.0	22.2	23.6	24.8	25.6	26.0	25.9
10	α Tauri	4 31	8.0	7.9	7.4	6.9	6.7	6.9	7.4	8.3	9.3	10.2	10.9	11.5	11.7
11	α Aurigæ	5 10	31.8	31.7	31.1	30.4	29.9	29.9	30.5	31.6	32.8	34.1	35.3	36.1	36.5
12	β Orionis	5 10	32.1	32.0	31.5	31.0	30.7	30.6	31.1	31.7	32.7	33.5	34.3	34.9	35.1
13	γ Orionis	5 20	39.6	39.6	39.2	38.7	38.4	38.3	38.8	39.5	40.4	41.3	42.1	42.7	43.1
14	ε Orionis	5 31	59.2	59.1	58.7	58.2	57.8	57.8	58.2	58.8	59.7	60.6	61.4	62.0	62.4
15	α Orionis	5 50	39.7	39.7	39.3	38.8	38.4	38.3	38.7	39.3	40.2	41.1	42.0	42.6	43.1
16	α Argus	6 22	7.8	7.5	6.7	5.6	4.6	4.1	4.0	4.5	5.5	6.7	7.9	8.8	9.2
17	α Can. Maj.	6 41	28.8	28.9	28.5	28.0	27.5	27.2	27.3	27.8	28.6	29.5	30.3	31.1	31.6
18	ε Can. Maj.	6 55	21.6	21.6	21.3	20.7	20.1	19.7	19.7	20.1	20.9	21.8	22.7	23.5	24.1
19	α Can. Min.	7 34	56.5	56.8	56.6	56.2	55.7	55.5	55.5	55.9	56.5	57.3	58.2	59.1	59.7
20	β Gemin.	7 40	13.2	13.6	13.5	13.0	12.5	12.2	12.2	12.6	13.4	14.3	15.3	16.3	17.1
21	ε Argus	8 20	49.9	50.2	49.8	48.7	47.5	46.5	45.9	45.7	46.4	47.4	48.9	50.4	51.4
22	λ Argus	9 4	56.2	56.7	56.7	56.2	55.5	54.8	54.5	54.3	54.7	55.4	56.5	57.7	58.6
23	β Argus	9 12	19.5	20.2	19.9	18.7	17.0	15.4	14.0	13.4	13.7	14.9	16.9	18.9	20.6
24	α Hydræ	9 23	29.4	30.0	30.1	29.9	29.5	29.1	28.9	28.9	29.2	29.8	30.7	31.6	32.5
25	α Leonis	10 3	55.8	56.5	56.8	56.7	56.4	56.1	55.8	55.7	56.0	56.4	57.2	58.2	59.2
26	α Urs. Maj.	10 58	36.3	37.8	38.5	38.4	37.6	36.6	35.7	35.1	34.9	35.4	36.5	38.1	40.0
27	β Leonis	11 44	47.8	48.8	49.3	49.5	49.4	49.1	48.8	48.6	48.5	48.6	49.1	50.1	51.0
28	α Crucis	12 21	55.3	57.0	58.0	58.5	58.4	57.7	56.8	55.8	55.1	55.0	55.8	57.3	59.2
29	γ Crucis	12 26	30.2	31.7	32.6	33.1	33.1	32.5	31.8	31.1	30.5	30.5	31.1	32.4	34.0
30	β Crucis	12 42	48.5	50.1	51.2	51.8	51.8	51.3	50.6	49.7	49.1	48.9	49.5	50.7	52.5
31	ε Urs. Maj.	12 50	21.4	22.9	24.0	24.5	24.4	23.7	23.0	22.1	21.5	21.2	21.6	22.6	24.0
32	ζ Urs. Maj.	13 20	33.5	35.0	36.1	36.8	36.8	36.3	35.6	34.7	34.0	33.6	33.8	34.6	35.9
33	α Virginis	13 20	46.4	47.5	48.2	48.7	48.9	48.9	48.7	48.4	48.1	47.9	48.2	48.9	49.8
34	θ Centauri	14 1	44.1	45.4	46.3	47.0	47.4	47.5	47.3	46.8	46.4	46.1	46.2	46.9	48.0
35	α Bootis	14 11	50.0	51.1	51.9	52.6	52.9	52.9	52.7	52.3	51.9	51.6	51.6	52.0	52.9

Declination.

No.	°	Jan. 1.	Feb. 1.	Mar. 1.	Apr. 1.	May 1.	June 1.	July 1.	Aug. 1.	Sept. 1.	Oct. 1.	Nov. 1.	Dec. 1.	Dec. 32.	Special Name.	Mag.
	°	′	′	′	′	′	′	′	′	′	′	′	′	′		
1	+28	37.8	37.8	37.7	37.6	37.6	37.6	37.7	37.8	38.0	38.1	38.2	38.2	38.2	Alpheratz	2.2
2	+58	41.6	41.5	41.4	41.2	41.1	41.1	41.2	41.3	41.5	41.6	41.8	41.9	41.9	Caph	2.4
3	−18	26.9	26.9	26.9	26.8	26.7	26.6	26.4	26.4	26.3	26.4	26.4	26.5	26.5	Deneb Kaitos	2.2
4	+59	48.3	48.3	48.2	48.8	48.0	47.9	47.9	48.0	48.2	48.3	48.5	48.6	48.7	Ruchbah	2.8
5	+88	51.9	51.9	51.8	51.7	51.5	51.4	51.4	51.4	51.5	51.7	51.9	52.1	52.2	Polaris	2.1
6	−57	40.0	40.0	39.9	39.7	39.5	39.4	39.2	39.2	39.2	39.3	39.5	39.6	39.7	Achernar	0.6
7	+23	4.2	4.1	4.1	4.1	4.0	4.1	4.1	4.2	4.3	4.4	4.4	4.5	4.5	Hamal	2.2
8	−40	38.5	38.6	38.5	38.5	38.3	38.2	38.0	37.9	37.9	37.9	38.0	38.2	38.3	Acamar	3.0
9	+49	34.1	34.1	34.1	34.0	33.9	33.9	33.8	33.9	33.9	34.0	34.1	34.2	34.3		1.9
10	+16	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.7	20.7	20.7	20.7	20.7	20.7	Aldebaran	1.1
11	+45	55.0	55.1	55.1	55.1	55.0	54.9	54.9	54.8	54.8	54.9	54.9	55.0	55.0	Capella	0.2
12	− 8	17.8	17.9	17.9	17.9	17.9	17.8	17.7	17.6	17.6	17.6	17.6	17.7	17.8	Rigel	0.3
13	+ 6	16.6	16.5	16.5	16.5	16.5	16.5	16.6	16.6	16.7	16.7	16.7	16.6	16.6	Bellatrix	1.7
14	− 1	15.2	15.3	15.3	15.3	15.3	15.2	15.2	15.1	15.0	15.0	15.1	15.1	15.2	Alnitam	1.8
15	+ 7	23.6	23.6	23.6	23.6	23.6	23.6	23.6	23.7	23.7	23.7	23.7	23.6	23.6	Betelgeux	1.0-1.4
16	−52	38.9	39.1	39.2	39.2	39.2	39.0	38.9	38.7	38.6	38.6	38.7	38.8	39.0	Canopus	−0.9
17	−16	36.0	36.1	36.2	36.2	36.2	36.1	36.0	35.9	35.8	35.8	35.9	36.0	36.1	Sirius	−1.6
18	−28	51.4	51.5	51.6	51.6	51.6	51.5	51.4	51.3	51.2	51.2	51.2	51.3	51.5	Adhara	1.6
19	+ 5	26.5	26.4	26.4	26.4	26.4	26.4	26.4	26.5	26.5	26.5	26.4	26.4	26.3	Procyon	0.5
20	+28	13.8	13.8	13.8	13.8	13.9	13.8	13.8	13.8	13.7	13.7	13.6	13.6	13.6	Pollux	1.2
21	−59	14.2	14.4	14.6	14.7	14.7	14.7	14.5	14.4	14.2	14.2	14.2	14.3	14.4		1.7
22	−43	5.5	5.6	5.8	5.9	6.0	5.9	5.8	5.7	5.6	5.5	5.5	5.6	5.7		2.2
23	−69	22.1	22.3	22.5	22.6	22.7	22.7	22.6	22.5	22.3	22.2	22.2	22.2	22.4	Miaplacidus	1.8
24	− 8	17.6	17.8	17.8	17.9	17.9	17.9	17.8	17.8	17.7	17.7	17.7	17.8	17.9	Alphard	2.2
25	+12	22.6	22.5	22.5	22.5	22.5	22.6	22.6	22.6	22.6	22.5	22.4	22.3	22.2	Regulus	1.3
26	+62	11.9	12.0	12.1	12.2	12.3	12.4	12.3	12.2	12.1	11.9	11.7	11.6	11.6	Dubhe	2.0
27	+15	2.3	2.2	2.2	2.2	2.3	2.3	2.3	2.4	2.3	2.3	2.2	2.0	31.9	Denebola	2.2
28	−62	37.8	38.0	38.1	38.3	38.5	38.6	38.6	38.6	38.5	38.3	38.2	38.2	38.2	Acrux	1.1
29	−56	38.4	38.5	38.7	38.9	39.0	39.1	39.1	39.1	39.0	38.9	38.8	38.7	38.8		1.6
30	−59	13.6	13.7	13.9	14.1	14.2	14.3	14.3	14.3	14.2	14.1	14.0	38.8	14.0		1.5
31	+56	24.5	24.5	14.5	24.7	24.8	24.9	25.0	24.9	24.8	24.7	24.5	24.3	24.2	Alioth	1.7
32	+55	21.4	21.4	21.4	21.5	21.7	21.8	21.8	21.8	21.7	21.6	21.4	21.2	21.1	Mizar	2.2
33	−10	43.5	43.6	43.7	43.7	43.7	43.7	43.7	43.7	43.6	43.6	43.6	43.7	43.8	Spica	1.2
34	−35	57.4	57.5	77.6	57.7	57.8	57.8	57.9	57.9	57.8	57.7	57.7	57.7	57.7		2.3
35	+19	36.9	36.8	36.8	36.8	36.9	36.9	37.0	37.0	37.0	37.0	36.9	36.7	36.6	Arcturus	0.2

TABLE IV.

PROPORTIONAL PARTS.

Interval 2 hours.	0	10	20	30	40	50	60	70	80	90	100	110	120	Interval 24 hours.
m														h m
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 0
1	0	0	0	0	0	0	0	1	1	1	1	1	1	12
2	0	0	0	0	1	1	1	1	1	2	2	2	2	24
3	0	0	0	1	1	1	2	2	2	2	2	3	3	36
4	0	0	1	1	1	2	2	2	3	3	3	4	4	48
5	0	0	1	1	2	2	2	3	3	4	4	5	5	1 0
6	0	0	1	2	2	2	3	4	4	4	5	6	6	12
7	0	1	1	2	2	3	4	4	5	5	6	6	7	24
8	0	1	1	2	3	3	4	5	5	6	7	7	8	36
9	0	1	2	2	3	4	4	5	6	7	8	8	9	48
10	0	1	2	2	3	4	5	6	7	8	8	9	10	2 0
11	0	1	2	3	4	5	6	6	7	8	9	10	11	12
12	0	1	2	3	4	5	6	7	8	9	10	11	12	24
13	0	1	2	3	4	5	6	8	9	10	11	12	13	36
14	0	1	2	4	5	6	7	8	9	10	12	13	14	48
15	0	1	2	4	5	6	8	9	10	11	12	14	15	3 0
16	0	1	3	4	5	7	8	9	11	12	13	15	16	12
17	0	1	3	4	6	7	8	10	11	13	14	16	17	24
18	0	2	3	4	6	8	9	10	12	14	15	16	18	36
19	0	2	3	5	6	8	10	11	13	14	16	17	19	48
20	0	2	3	5	7	8	10	12	13	15	17	18	20	4 0
21	0	2	4	5	7	9	10	12	14	16	18	19	21	12
22	0	2	4	6	7	9	11	13	15	16	18	20	22	24
23	0	2	4	6	8	10	12	13	15	17	19	21	23	36
24	0	2	4	6	8	10	12	14	16	18	20	22	24	48
25	0	2	4	6	8	10	12	15	17	19	21	23	25	5 0
26	0	2	4	6	9	11	13	15	17	20	22	24	26	12
27	0	2	4	7	9	11	14	16	18	20	22	25	27	24
28	0	2	5	7	9	12	14	16	19	21	23	26	28	36
29	0	2	5	7	10	12	14	17	19	22	24	27	29	48
30	0	2	5	8	10	12	15	18	20	22	25	28	30	6 0
31	0	3	5	8	10	13	16	18	21	23	26	28	31	12
32	0	3	5	8	11	13	16	19	21	24	27	29	32	24
33	0	3	6	8	11	14	16	19	22	25	28	30	33	36
34	0	3	6	8	11	14	17	20	23	26	28	31	34	48
35	0	3	6	9	12	15	18	20	23	26	29	32	35	7 0
36	0	3	6	9	12	15	18	21	24	27	30	33	36	12
37	0	3	6	9	12	15	18	22	25	28	31	34	37	24
38	0	3	6	10	13	16	19	22	25	28	32	35	38	36
39	0	3	6	10	13	16	20	23	26	29	32	36	39	48
40	0	3	7	10	13	17	20	23	27	30	33	37	40	8 0
41	0	3	7	10	14	17	20	24	27	31	34	38	41	12
42	0	4	7	10	14	18	21	24	28	32	35	38	42	24
43	0	4	7	11	14	18	22	25	29	32	36	39	43	36
44	0	4	7	11	15	18	22	26	29	33	37	40	44	48

Find the correction to be applied to the right ascension and declination of Jupiter on April 15, 1916, at $11^h\ 55^m\ 30^s$ a. m. local mean time, in Long. 81° 15′ W.
(Problem page 107.)

G. M. T. $=15^d\ 5^h\ 20^m.5$.

Difference of R. A. in $24^h=54$. Difference for Dec. in $24^h=55$.

With differences of 54 for R. A. and 55 for Dec. as arguments at top of page and the G. M. T. as argument at right-hand side of page.

Corr. R. A., for 50; $5^h\ 12^m=$		11^s	Corr. Dec., for 50; $5^h\ 12^m=$		1′.1
Corr. for 54=	$+0^s.8$		Corr. for 55=	+0′.1	
Corr. for $5^h\ 20^m.5=$	$+0^s.3$		Corr. for $5^h\ 20^m.5=$	0′.0	
Total	$+1^s.1$	$1^s.1$	Total	+0′.1	+0′.1
R. A. (correction)........		$+12^s.1$	Dec. (correction)..........		+1.′2

APPENDIX II.

A COLLECTION OF FORMS FOR WORKING DEAD RECKONING AND VARIOUS ASTRONOMICAL SIGHTS, WITH NOTES EXPLAINING THEIR APPLICATION UNDER ALL CIRCUMSTANCES.

(The figures in parenthesis refer to the Notes following these forms.)

FORM FOR DAY'S WORK, DEAD RECKONING.

Time.	Compass Course.	Var.	Dev.	Lee-way.	Total error.	True Course.	Patent log.	Dist.	N.	S.	E.	W.	Diff. (1) Long.

	Latitude. ° ′		*Longitude.* ° ′	
Left at departure (or noon)	......	(2) N. *or* S.	......	(2) E. *or* W.
Run to......	......	N. *or* S.	......	E. *or* W.
By D. R. at......	......	N. *or* S.	......	E. *or* W.
Run to......	......	N. *or* S.	......	E. *or* W.
By D. R. at......	......	N. *or* S.	......	E. *or* W.

FORM FOR TIME SIGHT OF SUN'S LOWER LIMB (SUMNER LINE).

	h. m. s.
W. T.	....
C–W	+ ....
Chro. t.	....
C. C.	± ....
(10) G. M. T.	....
(6) Eq. t.	± ....
G. A. T.	....

	° ′ ″
Obs. alt. ⊙	....
Corr.	± ....
h	....
	′ ″
(3) S. D.	+ ....
(4) I. C.	+ ....
	+ ....
	′ ″
dip	− ....
p. & r.	− ....
	− ....
	′ ″
Corr.	± ....

	° ′ ″
Dec.	.... N. *or* S.
	″
H. D.	± ....
	h.
G. M. T.	....
	′ ″
Corr.	± ....
	° ′ ″
Dec.	.... N. *or* S.
	° ′ ″
(5) *p*	....

	m. s.
Eq. t.	....
	s.
H. D.	± ....
	h.
G. M. T.	....
	s.
Corr.	± ....
	m. s.
Eq. t.	....

	° ′ ″		
h	....		
L_4	....	log sec	....
p	....	log cosec	....
	2)..........		
s_1	....	log cos	....
$s_1 - h$	....	log sin	....
			2)..........
	h. m. s.		
G. A. T.	....		
L. A. T.₁	....	log sin $\frac{1}{2} t_1$	....

(7) Long.₁ {h. m. s. ....; ° ′ ″ ....; ....} E. *or* W.

	° ′ ″		
(8) L_2	....	log sec	....
		log cosec	....
(9) s_2	....	log cos	....
$s_2 - h$	....	log sin	....
			2)..........
	h. m. s.		
G. A. T.	....		
L. A. T.₂	....	log sin $\frac{1}{2} t_2$	....

Long.₂ {h. m. s. ....; ° ′ ″ ....; ....} E. *or* W.

FORM FOR TIME SIGHT OF A STAR (SUMNER LINE).

	h. m. s.		° ′ ″		h. m. s.
W. T.	....	Obs. alt.	✱	R. A.	....
C–W	+	Corr.	±		° ′ ″
Chro. t.	....	h	....	Dec.	.... N. or S.
C. C.	±		′ ″		° ′ ″
(10) G. M. T.	....	(4) I. C	+	(8) p	....
R. A. M. S.	+		′ ″		
Red. (Tab. 9)	+				
		dip	−		
G. S. T.	....	ref.	−		
R. A. ✱	....				
			−		
(11) H. A. from Gr.	.... E. or W.		′ ″		
		Corr.	±		

	° ′ ″				° ′ ″		
h	....						
L_1	....	log sec	....	(8) L_2	....	log sec	....
p	....	log cosec	....			log cosec	....
	2)..............						
s_1	....	log cos	....	(9) s_2	....	log cos	....
s_1-h	....	log sin	....	s_2-h	....	log sin	....
	h. m. s.		2)..........		h. m. s.		2)..........
Gr. H. A.	....	E. or W.		Gr. H. A.	....		
(12) H. A.₁	....	E. or W. log sin ½ t_1	....	H. A.₂	....	log sin ½ t_2	....
(13) Long.₁	h. m. s. .... ° ′ ″	E. or W.		Long.₂	h. m. s. .... ° ′ ″	E. or W.	

FORM FOR TIME SIGHT OF A PLANET (SUMNER LINE).

	h. m. s.		° ′ ″		h. m. s.		° ′ ″
W. T.	....	Obs. alt.	✱.......	R. A.	....	Dec.	.......N. or S.
C–W	+.......	Corr.	±.......		s.		″
Chro. t.	....	h	....	H. D.	±.......	H. D.	±.......
C. C.	±.......		′ ″		h.		h.
(10) G. M. T.	....	(14) par.	+.......	G. M. T	....	G. M. T	....
R. A. M. S.	+.......	(4) I. C.	+.......		s.		′ ″
Red. (Tab. 9)	+.......			Corr.	±.......	Corr.	±.......
			+.......		h. m. s.		° ′ ″
G. S. T.	....		′ ″				
R. A. ✱	....			R. A.	....	Dec.	.......N. or S.
		dip	−.......				° ′ ″
(11) H. A. from Gr.	.......E. or W.	ref.	−.......			(8) p	....
			−.......				
			′ ″				
		Corr.	±.......				

For the remainder of the work, by which the hour angles and thence the longitudes are found, employ the method given under "Form for Time Sight of a Star (Sumner Line)."

FORM FOR TIME SIGHT OF MOON'S LOWER LIMB (SUMNER LINE).

	h. m. s.		° ′ ″		h. m. s.		° ′ ″
W. T.	....	Obs. alt.	☾.......	(16) R. A.	....	(16) Dec.	.... N. or S.
C—W	+.......						
			′ ″		s.		″
Chro. t.	....	(15) S. D.	+.......	H. D.	+.......	H. D.	±.......
C. C.	±.......	Aug.	+.......		m.		m.
		(4) I. C.	+.......	G. M. T.	±.......	G. M. T.	±.......
(10) G. M. T.	....						
R. A. M. S.	+.......		+.......		s.		′ ″
Red. (Tab. 9)	+.......			Corr.	±.......	Corr.	±.......
			′ ″		h. m. s.		° ′ ″
G. S. T.	....	dip	−.......				
R. A. ☾	....			R. A.	....	Dec.	.... N. or S.
			′ ″				
(11) H. A. from Gr.	.... E. or W.	1st corr.	±.......			(5) p	....
			° ′ ″				
		Approx. alt.	....				
		p. & r. (Tab. 24)	+.......				
		h	....				

For the remainder of the work, by which the hour angles and thence the longitudes are found, employ the method given under "Form for Time Sight of a Star (Sumner Line)."

FORM FOR MERIDIAN ALTITUDE OF SUN'S LOWER LIMB.

	° ′ ″		′ ″		h. m. s.		° ′ ″
Obs. alt.	☉.......	(3) S. D.	+.......	L. A. T.	....	Dec.	.... N. or S.
Corr.	±.......	(4) I. C.	+.......	Long.	....		
							″
h	....		+.......	G. A. T.	....	H. D.	±.......
	° ′ ″		′ ″	Eq. t.	....		h.
(17) z	.... N. or S.	dip.	−.......	G. M. T.	....	G. M. T.	±.......
d	.... N. or S.	p. & r.	−.......				′ ″
Lat.	.... N. or S.		−.......			Corr.	±.......
			′ ″				° ′ ″
		Corr.	±.......			Dec.	.... N. or S.

FORM FOR MERIDIAN ALTITUDE OF A STAR.

	° ′ ″		′ ″		° ′ ″
Obs. alt.	✱.......	(4) I. C.	+.......	Dec.	.... N. or S.
Corr.	±.......		′ ″		
h	....	dip	−.......		
		ref.	−.......		
(17) z	.... N. or S.				
d	.... N. or S.		−.......		
			′ ″		
Lat.	.... N. or S.	Corr.	±.......		

FORM FOR MERIDIAN ALTITUDE OF A PLANET.

	° ′ ″		′ ″		h. m.		° ′ ″
Obs. alt.	✱.......	(14) par.	+.......	G. M. T., Gr. trans.	....	Dec.	.... N. or S.
Corr.	±.......	(4) I. C.	+.......	Corr. for Long.	±.......		″
h	....		+.......	L. M. T., local trans.	....	H. D.	±.......
	° ′ ″		′ ″	Long.	±.......		h.
(17) z	.... N. or S.	dip	−.......	G. M. T., local trans.	....	G. M. T.	....
d	.... N. or S.	ref.	−.......				′ ″
Lat.	.... N. or S.		−.......			Corr.	±.......
			′ ″				° ′ ″
		Corr.	±.......			Dec.	.... N. or S.

FORM FOR MERIDIAN ALTITUDE OF MOON'S LOWER LIMB.

	° ′ ″		° ′ ″		h. m.		° ′ ″
h	....	Obs. alt. ☾	....	G. M. T., Gr. trans.	.....	(16) Dec.	.... N. or S.
	° ′ ″		′ ″	Corr. for Long. (Tab.11)	±		″
(17) z	.... N. or S.	(15) S. D.	+	L. M. T., local trans.	.....	H. D.	± ....
d	.... N. or S.	Aug.	+	Long.	±		m.
		(4) I. C.	+			G. M. T.	± ....
Lat.	.... N. or S.		+	G. M. T., local trans.	.....		′ ″
			′ ″			Corr.	± ....
		dip	−				° ′ ″
			′ ″			Dec.	.... N. or S.
		1st corr	±				
			° ′ ″				
		Approx. Alt.	....				
		p.&r. (Tab.24)	+				
		h	....				

ALTERNATIVE FORM FOR MERIDIAN ALTITUDE OF A BODY. (18)

	± 90° 00′ 00″
(19) Dec.	± ....
Corr.	± ....
Constant	± ....
Obs. Alt.	± ....
Lat.	.... N. or S.

Rules for signs.

Case I.	Lat. & Dec. same name, Lat. greater	+90°+Dec.−Corr.−Alt.
Case II.	Lat. & Dec. same name, Dec. greater	−90°+Dec.+Corr.+Alt.
Case III.	Lat. and Dec. opposite names	+90°−Dec.−Corr.−Alt.
Case IV.	Lower transit	+90°−Dec.+Corr.+Alt.

FORM FOR LATITUDE SIGHTS OF SUN'S LOWER LIMB (SUMNER LINE).

	h. m. s.		° ′ ″		° ′ ″		m. s.
W. T.	....	Obs. alt. ☉	....	Dec.	.... N. or S.	Eq. t.	....
C−W	±	Corr.	±		″		s.
Chro. t.	....	h	....	H. D.	±	H. D.	± ....
C. C.	±		′ ″		h.		h.
(10) G. M. T.	....	(3) S. D.	+	G. M. T.	....	G. M. T.	....
(9) Eq. t.	±	(4) I. C.	+		′ ″		s.
G. A. T.	....		+	Corr.	±	Corr.	± ....
Long.₁	±		′ ″		° ′ ″		m. s.
L. A. T.₁	....	dip	−	Dec.	.... N. or S.	Eq. t.	....
	h. m. s.	*p. & r.*	−				
(20) t_1	....		−				
	° ′ ″		′ ″				
	....	Corr.	±				
	h. m. s.						
(21) Long.₂	±						
L. A. T.₂	....						
	h. m. s.						
t_2	....						
	° ′ ″						
	....						

φ′ φ″ Method.

	° ′ ″		
t_1	....	log sec	
d	....	log tan	log cosec ......
h	....		log sin ....
(22) φ_1''	.... N. or S.	log tan	log sin ....
φ_1'	.... N. or S.		log cos ....
Lat.₁	.... N. or S.		
	° ′ ″		
t_2	....	log sec	
d	....	log tan	log cosec ......
h	....		log sin ....
φ_2''	.... N. or S.	log tan	log sin ....
φ_2'	.... N. or S.		log cos ....
Lat.₂	.... N. or S.		

Reduction to Meridian.

	″		
(23) a	....		
	° ′ ″		° ′ ″
h	....	h	....
(24) at_1^2	±	at_2^2	± ....
H_1	....	H_2	....
	° ′ ″		° ′ ″
(17) z_1	.... N. or S.	z_2	....
d	.... N. or S.	d	....
Lat.₁	.... N. or S.	Lat.₂	.... N. or S.

FORM FOR LATITUDE SIGHTS OF A STAR (SUMNER LINE).

		h. m. s.	
W. T.		....	
C-W	+	....	
Chro. t.		....	
C. C.	±	....	
(10) G. M. T.		....	
R. A. M. S.	+	....	
Red. (Tab.9)	+	....	
G. S. T.		....	
R. A.*		....	
(11) H. A. from Gr.		....	E. or W.
(26) Long.₁		....	E. or W.
t_1		h. m. s. .... ° ′ ″	E. or W.
		h. m. s.	
(26) Long.₂		....	E. or W.
t_2		h. m. s. .... ° ′ ″	E. or W.

		° ′ ″
Obs. alt.*		....
Corr.	±	....
h		....
		′ ″
(4) I. C.	+	....
		′ ″
dip	−	....
ref.	−	....
	−	....
		′ ″
Corr.	±	....

	h. m. s.	
R. A.	....	
	° ′ ″	
Dec.	....	N. or S.

For the remainder of the work, by which the latitudes are found from either the φ′ φ″ formula or the reduction to the meridian, employ the methods given under "Form for Latitude Sights of Sun's Lower Limb (Sumner Line)."

FORM FOR LATITUDE SIGHTS OF A PLANET (SUMNER LINE).

		h. m. s.	
W. T.		....	
C-W	+	....	
Chro. t.		....	
C. C.	±	....	
(10) G. M. T.		....	
R. A. M. S.	+	....	
Red. (Tab.9)	+	....	
G. S. T.		....	
R. A.*		....	
(11) H. A. from Gr.		....	E. or W.
(26) Long.₁		....	E. or W.
t_1		h. m. s. .... ° ′ ″	E. or W.
		h. m. s.	
(26) Long.₂		....	E. or W.
t_2		h. m. s. .... ° ′ ″	E. or W.

		° ′ ″
Obs. alt.*		....
Corr.	±	....
h		....
		′ ″
(14) par.	+	....
(4) I. C.	+	....
	+	....
		′ ″
dip	−	....
ref.	−	....
	−	....
Corr.	±	....

		h. m. s.			° ′ ″	
R. A.		....	Dec.		....	N. or S.
		s.			″	
H. D.	±	....	H. D.	±	....	
		h.			h.	
G. M. T.		....	G. M. T.		....	
		s.			′ ″	
Corr.	±	....	Corr.	±	....	
		h. m. s.			° ′ ″	
R. A.		....	Dec.		....	N or S.

For the remainder of the work, by which the latitudes are found from either the φ′ φ″ formula or the reduction to the meridian, employ the methods given under "Forms for Latitude Sights of Sun's Lower Limb (Sumner Line)."

FORM FOR LATITUDE SIGHTS OF MOON'S LOWER LIMB (SUMNER LINE).

		h. m. s.	
	W. T.	....	
	C–W	+..........	
	Chro. t.	....	
	C. C.	±..........	
(10)	G. M. T.	....	
	R. A. M. S.	+..........	
	Red. (Tab. 9)	+..........	
	G. S. T.	....	
	R. A. ☾	....	
(11)	H. A. from Gr.	....	E. *or* W.
(25)	Long.₁	....	E. *or* W.
	t_1	h. m. s. .... ° ′ ″	E. *or* W.
		h. m. s.	
	Long.₂	....	E. *or* W.
	t_2	h. m. s. .... ° ′ ″	E. *or* W.

		° ′ ″
	Obs. alt. ☾	....
		′ ″
(15)	S. D.	+........
	Aug.	+........
(4)	I. C.	+........
		+........
		′ ″
	dip	−........
		′ ″
	1st Corr.	±........
		° ′ ″
	Approx. alt.	....
	p. & r. (Tab. 24)	+........
		° ′ ″
	h	....

		h. m. s.		° ′ ″
(16) R. A.	....		(16) Dec.	......N. *or* S.
	s.			″
H. D.	+........		H. D.	±......
	m.			m.
G. M. T.	±........		G. M. T.	±......
	s.			′ ″
Corr.	±........		Corr.	±......
	h. m. s.			° ′ ″
R. A.	....		Dec.	......N. *or* S.

For the remainder of the work, by which the latitudes are found from either the φ′ φ″ formula or the reduction to the meridian, employ the methods given under "Forms for Latitude Sights of Sun's Lower Limb (Sumner Line)."

FORM FOR FINDING THE TIME OF HIGH (OR LOW) WATER.

	d. h. m.
G. M. T. of Greenwich transit	....
Corr. for Long. (Tab. 11)	±...........
L. M. T. of local transit	....
Lunitidal int. (App. IV)	+...........
L. M. T. of high (or low) water	....

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF THE SUN'S LOWER LIMB.

(SINE—COSINE FORMULA.[1])

		h. m. s.				° ′ ″				m. s.
W. T.		....		Dec.		....	N. or S.	Eq. t.		....
C-W	+	....				″				s.
				H. D.	±	....		H. D.	±	....
Chro. t.		....				h.				h.
C. C.	±	....		G. M. T.		....		G. M. T.		....
						′ ″				s.
(10) G. M. T.		....		Corr.	±	....		Corr.	±	....
(6) Eq. t.	±	....				° ′ ″				m. s.
G. A. T.		....		d		....	±	Eq. t.		....
		....								
Long. of assumed Pos.		....	E. or W.							
		h. m. s.								
L. A. T.=t		....	=							
		° ′ ″								
Obs. alt.	⊙	....								
I. C.	+	....								
Corr. (Tab. 46)	±	....								
Obs. h		....								
Calculated h		....								
Alt. Diff.		....								

	° ′ ″				
	....			log cos	±
L ±	....	log sin	.... ±	log cos	
d ±	....	log sin	.... ±	log cos	
		(Sum) log A	.... ±	log B	±
		A ±	....	B ±	
				A ±	
Calculated h	....	nat. sin	=	A + B	

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF THE SUN'S LOWER LIMB.

(COSINE—HAVERSINE FORMULA.[2])

		h. m. s.				° ′ ″				m. s.
W. T.		....		Dec.		....	N. or S.	Eq. t.		....
C—W.	+	....		H. D.	±	″				s.
						....		H. D.	±	....
Chro. t.		....				h				h.
C. C.	±	....		G. M. T.		....		G. M. T.		....
						′ ″				s.
(10) G. M. T.		....		Corr.	±	....		Corr.	±	....
(6) Eq. t.	±	....				° ′ ″				m. s.
G. A. T.		....		d	±	....		Eq. t.		....
Long. of assumed Pos.		....	E. or W.							
		h. m. s.								° ′ ″
L. A. T.=t		....		log hav		....		Obs. alt.	⊙	....
		° ′ ″								
L		....		log cos		....		I. C.	+	....
d		....		log cos		....		Corr. (Tab. 46).	±	....
				log hav θ		....	(Sum)	Obs. h		....
				nat hav θ		.... }		Calculated h		....
L∼d		....		nat hav		.... }		Alt. Diff.		....
z		....		nat hav		....	(Sum)			
Calculated h =90°−z		....								

[1] Sine—cosine formula: $\sin h = \sin L \sin d + \cos L \cos d \cos t$
$= \quad A \quad + \quad B$

[2] Cosine—haversine formula: $\text{hav } z = \text{hav } (L \sim d) + \cos L \cos d \text{ hav } t$
$= \text{hav } (L \sim d) + \text{hav } \theta$

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF THE SUN'S LOWER LIMB.

(27) (HAVERSINE FORMULA.[1])

		h. m. s.				° ′ ″				m. s.
W. T.		....		Dec.		....	N. or S.	Eq. t.		....
C—W	+	....				″				s
Chro. t.		....		H. D.	±	....		H. D.	±	....
C. C.	±	....				h				h
(10) G. M. T.		....		G. M. T.		....		G. M. T.		....
(6) Eq. t.	±	....				′ ″				s
G. A. T.		....		Corr	±	....		Corr	±	....
						° ′ ″				m. s.
Long of assumed Pos.		....	E. or W.	Dec.		....	N. or S.	Eq. t.		....
L. A. T.=t		....				° ′ ″				
				(6) P. D.		....				
				co. L.		....				
				co. L.+ P. D.		....	nat hav			....
				co. L.− P. D.		....	nat hav			....

		° ′ ″		
			nat hav A	.... (Diff.)
			log hav A	....
			log hav t	....
			log hav B	.... (Sum)
Obs. Alt.	⊙	....	nat hav B	....
I. C.	+	....	nat hav (co. L−P. D.)	....
Corr. (Tab. 46)	±	....	nat hav z	.... (Sum)
Obs. h		....		° ′ ″
Calculated h		....	z	....
Alt. Diff.		....	Calculated h = 90°−z	....

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF A STAR.

(SINE-COSINE FORMULA.[2])

	h. m. s.			° ′ ″					° ′ ″	
W. T.	....		Obs. alt. ✱	....			Dec. (d)		....	N. or S
C-W	+..........		I. C.	+..........					h. m. s.	
			Corr. (Tab. 46)	−..........			R. A.		....	
Chro. t.	....									
C. C.	±..........		Obs. h	....						
				° ′ ″						
(10) G. M. T,	....		t	....		....		log cos		..........±
R. A. M. S,	+..........		L ±	....	log sin	........±		log cos		....
Red. (Tab. 9)	+..........		d ±	....	log sin	........±		log cos		....
G. S. T.	....			(Sum)	log A	........±		log B		..........±
R. A.✱	....				A ±	....		B ±		....
				° ′ ″				A ±		....
(11) H. A.✱ from Gr.	....	E. or W.	Calculated h	....						
(25) Long. of assumed Pos.	....	E. or W.	Obs. h	....						
t	h. m. s. / ° ′ ″		Alt. Diff.	....	nat sin=	A+B				....

[1] Haversine formula: hav z = {hav (co. L + P. D.)− hav (co. L−P. D.)}hav t + hav (co. L−P. D.)
= hav B + hav (co. L−P. D.); where hav B=hav A hav t, and hav A=hav (co. L+ P. D.)−hav (co. L−P. D.)

[2] Sine—cosine formula: sin h =sin L sin d + cos L cos d cos t
= A + B

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF A STAR.

(COSINE-HAVERSINE FORMULA.[1])

	h. m. s.		h. m. s.				
W. T.	....	t	....	log hav		Dec. (d)	..........N. *or* S.
			° ′ ″				h. m. s.
C-W.	+..........	L	....	log cos		R. A.	....
Chro. t.	....	d	....	log cos			
							° ′ ″
C. C.	±..........			log hav θ..........	(Sum)	Obs. alt. *	....
(13) G. M. T.	....			nat hav θ..........		I. C.	+..........
R. A. M. S.	+..........	L∼d	....	nat hav		Corr. (Tab. 46)	−..........
Red. (Tab. 9)	+..........	z	....	nat hav	(Sum)	Obs. h	....
G. S. T.	....						
			° ′ ″				
R. A. *	....	Calculated h	....	=90°−z			
(11) H. A. * from Gr.	..........E. *or* W.	Obs. h	....				
(25) Long. of assumed Pos.	..........E. *or* W.	Alt. diff.	....				
t	....						

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF A STAR.

(27) (HAVERSINE FORMULA.[2])

	h. m. s.		° ′ ″				h. m. s.
W. T.	....	Dec.	..........N. *or* S.			R. A.	....
C-W	+..........	(9) P. D.	....				
							° ′ ″
Chro. t.	....	co. L.	....			Obs. alt. *	....
C. C.	±..........	co. L+P. D.	....	nat hav		I. C. +	....
(10) G. M. T.	....	co. L−P. D.	....	nat hav		Corr. (Tab. 46) −	....
R. A. M. S.	+..........			nat hav A..........	(Diff.)	Obs. h	....
Red. (Tab. 9)	+..........		h. m. s.	log hav A..........		Calculated h	....
G. S. T.	....	t	....	log hav..........		Alt. diff.	....
R. A. *	....			log hav B..........	(Sum)		
(11) H. A. * from Gr.	..........E. *or* W.			nat hav B..........			
			° ′ ″				
(25) Long. of assumed Pos.	..........E. *or* W.	co. L−P. D.	....	nat hav			
t	....	z	....	nat hav	(Sum)		
			° ′ ″				
		Calculated h =90°−z	....				

---

[1] Cosine—haversine formula: hav z = hav (L∼d) + cos L cos d hav t
= hav (L∼d) + hav θ

[2] Haversine formula: hav z = {hav (co. L + P. D.) − hav (co. L−P. D.)} hav t + hav (co. L−P. D.)
= hav B + hav (co. L−P. D.); where hav B = hav A hav t, and hav A = hav (co. L+P. D.) − hav (co. L−P. D.)

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF A PLANET.

(SINE-COSINE FORMULA[1])

	h. m. s.		h. m. s.		° ′ ″		° ″
W. T.	....	R. A.	....	Dec.	..........N. or S.	Obs. alt.	....
			s.		″		
C-W	+..........	H. D.	±..........	H. D.	±..........	I. C.	+..........
			h.		h.		
Chro. t.	....	G. M. T.	....	G. M. T.	....	Corr. (Tab. 46).	−..........
			s.		′ ″		
C. C.	±..........	Corr.	±..........	Corr.	±..........	Obs. h	....
(10) G. M. T.	....	R. A.	....	d	..........±	Calculated h	....
R. A. M. S.	+..........					Alt. Diff.	....
			° ′ ″				
Red. (Tab. 9)	+..........	t	....	....		log cos	........±
G. S. T.	....	L	±..........	log sin	..........±	log cos	....
R. A. ✱	....	d	±..........	log sin	..........±	log cos	....
(11) H. A. ✱ from Gr.	..........E. or W.			(Sum) log A	..........±	log B	........±
(25) Long. of assumed Pos.	..........E. or W.			A	±..........	B	±..........
t	h. m. s. / ° ′ ″		° ′ ″			A	±..........
		Calculated h	....	nat. sin		=A+B	....

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF A PLANET.

(COSINE-HAVERSINE FORMULA.[2])

	h. m. s.		h. m. s.				h. m. s.		° ′ ″
W. T.	....	t	....	log hav	....	R. A.	....	Dec.	..........N. or S.
			° ′ ″				s.		″
C-W	+..........	L	....	log cos	....	H. D.	±..........	H. D.	±..........
							h.		h.
Chro. t.	....	d	....	log cos	....	G. M. T.	....	G. M. T.	....
							s.		′ ″
C. C.	±..........			log hav θ	..........(Sum)	Corr.	±..........	Corr.	±..........
(10) G. M. T.	....			nat hav θ	....	R. A.	....	d	..........±
R. A. M. S.	+..........	L∼d	....	nat hav	....				
Red. (Tab. 9)	+..........	z	....	nat hav	..........(Sum)				
			° ′ ″						
G. S. T.	....								
R. A. ✱	....	Calculated h	..........=90°−z						
(11) H. A. ✱ from Gr.	....	E. or W.							
(25) Long. of assumed Pos.	....	E. or W.							
t	....								

	° ′ ″
Obs. alt.	....
I. C.	+..........
Corr. (Tab. 46)	−..........
Obs. h	....
Calculated h	....
Alt. Diff.	....

[1] Sine—cosine formula: $\sin h = \sin L \sin d + \cos L \cos d \cos t$
$= A + B$

[2] Cosine—haversine formula: $\text{hav } z = \text{hav } (L \sim d) + \cos L \cos d \text{ hav } t$
$= \text{hav } (L \sim d) + \text{hav } \theta$

FORM FOR FINDING THE CALCULATED ALTITUDE AND THE ALTITUDE DIFFERENCE FOR LAYING DOWN THE SUMNER LINE BY THE METHOD OF SAINT HILAIRE FROM A SIGHT OF A PLANET.

(27) (HAVERSINE FORMULA.)[1]

	h. m. s.			° ′ ″			° ′ ″		
W. T.	....		Dec.	....	N. or S.	co. L + P. D.	....	nat hav	....
				″					
C–W	+		H. D.	±		co. L − P. D.	....	nat hav	....
				h					
Chro. t.	....		G. M. T.	....				nat hav A.	........(Diff.)
				′ ″					
C. C.	±		Corr.	±				log hav A.	....
				° ′ ″			h. m. s.		
(10) G. M. T.	....		Dec.	....	N. or S.	t	....	log hav	....
R. A. M. S.	+		(5) P. D.	....				log hav B.	........(Sum)
Red. (Tab. 9)	+		co. L	....				nat hav B.	....
				° ′ ″			° ′ ″		
G. S. T.	....		co. L + P. D.	....		co. L − P. D.	....	nat hav	....
R. A. ✱	....		co. L − P. D.	....		z	....	nat hav	........(Sum)
				h. m. s.					
(11) H. A. ✱ from Gr.	....	E. or W.	R. A.	....					
				s.			° ′ ″		° ′ ″
(25) Long. of assumed Pos.	....	E. or W.	H. D.	±		Calculated h = 90° − z	....	Obs. alt.	....
				h.					
t	....		G. M. T.	....		Obs. h	....	I. C.	+ ....
				s.					
			Corr.	±		Alt. Diff.	....	Corr. − (Tab. 46)	....
				h. m. s.					
			R. A.	....				Obs. h	....

[1] Haversine formula: $\text{hav } z = \{\text{hav (co. L + P. D.)} - \text{hav (co. L} - \text{P. D.)}\} \text{ hav } t + \text{hav (co. L} - \text{P. D.)}$
$= \text{hav B} + \text{hav (co. L} - \text{P. D.)}$; where $\text{hav B} = \text{hav A hav } t$, and $\text{hav A} = \text{hav (co. L + P. D.)} - \text{hav (co. L} - \text{P. D.)}$

NOTES RELATING TO THE FORMS.

1. It is not necessary to convert departure into difference of longitude for each course; it will suffice to make one conversion for the sum of all the departures used in bringing forward the position to any particular time.

2. In D. R. it will be found convenient to work Lat. and Long. in minutes and tenths, rather than in minutes and seconds.

3. If upper limb is observed, the correction for S. D. should be negative, instead of positive.

4. A positive I. C. has been assumed for illustration throughout the forms; if negative, it should be included with the *minus* terms of the correction.

5. To obtain p, subtract Dec. from 90° if of same name as Lat.; add to 90° if of opposite name

6. Sign of Eq. t. that of application to *mean* time.

7. If G. A. T. is later than L. A. T., Long. is west; otherwise it is east.

8. If Lat. is exactly known, a second latitude need not be employed.

9. s_2 and $s_2 - h$ may be obtained by applying half the difference between L_1 and L^2 with proper sign, to s_1 and $s_1 - h$, respectively.

10. The G. M. T. must represent the proper number of hours from noon, the beginning of the astronomical day; to obtain this it may be necessary to add 12^h to the Chro. t.

11. H. A. from Greenwich is the difference between G. S. T. and R. A., and should be marked W. if the former is greater; otherwise, E.

12. Local H. A. is marked E. or W., according as the body is east or west of the meridian at time of observation.

13. Subtract local hour angle from Greenwich hour angle to obtain longitude; that is, change name of local hour angle and combine algebraically.

14. The forms include a correction for the parallax of a planet, but in most cases this is small, and may be omitted. When used, take hor. par. from Naut. Alm. and reduce to observe altitude by Table 17. The semidiameter of a planet may be disregarded in sextant work if the *center* of the body is brought to the horizon line.

15. If upper limb is observed, the corrections for S. D. and Aug. should be negative, instead of positive.

16. R. A. and Dec. are to be picked out of Naut. Alm. for nearest hour of G. M. T., and to be corrected for the number of minutes and tenths.

17. Mark zenith distance N. or S. according as zenith is north or south of the body observed; mark Dec. according to its name, subtracting it from 180° for cases of lower transit; then, in combining the two for Lat., have regard to their names.

18. This form enables "Constant" to be worked up before sight is taken, and gives latitude directly on completion of meridian observation. Longitude and altitude at transit must be known in advance with sufficient accuracy for correcting terms.

19. The details of obtaining Dec. at transit and correction for altitude are shown in the meridian altitude forms for each of the various bodies.

20. In an a. m. sight subtract L. A. T. from 24^h to obtain t; in a p. m. sight L. A. T. is equal to t.

21. If Long. is exactly known, a second longitude need not be employed.

22. Mark ϕ'' N. or S. according to name of Dec., and subtract it from 180° when body is nearer to lower than to upper transit; mark ϕ' N. or S. according as zenith is north or south of the body; then combine for Lat. having regard to the names

23. Take a from Table 26 and at^2 from Table 27.

24. Add for upper, subtract for lower transits.

25. Subtract longitude from Greenwich hour angle to obtain local hour angle; that is, change name of longitude and combine algebraically.

26. Add for west, subtract for east longitude.

27. As the trigonometric functions are all haversines in this solution, the abbreviation, hav, might be omitted, and the abbreviations, nat. and log, might be employed to indicate the natural haversine and the log haversine, respectively.

APPENDIX III.

EXPLANATION OF CERTAIN RULES AND PRINCIPLES OF MATHEMATICS OF USE IN THE SOLUTION OF PROBLEMS IN NAVIGATION.

DECIMAL FRACTIONS.

Fractions, or *Vulgar Fractions*, are expressions for any assignable part of a unit; they are usually denoted by two numbers, placed one above the other, with a line between them; thus $\frac{1}{4}$ denotes the fraction one-fourth, or one part out of four of some whole quantity, considered as divisible into four equal parts. The lower number, 4, is called the *denominator* of the fraction, showing into how many parts the whole is divided; and the upper number, 1, is called the *numerator*, and shows how many of those equal parts are contained in the fraction. It is evident that if the numerator and denominator be varied in the same ratio the value of the fraction will remain unaltered; thus, if both the numerator and denominator of the fraction $\frac{1}{4}$ be multiplied by 2, 3, 4, etc., the fractions arising will be $\frac{2}{8}$, $\frac{3}{12}$, $\frac{4}{16}$, etc., all of which are evidently equal to $\frac{1}{4}$.

A *Decimal Fraction* is a fraction whose denominator is always a unit with some number of ciphers annexed and the numerator any number whatever; as $\frac{2}{10}$, $\frac{3}{100}$, $\frac{16}{1000}$, etc. And as the denominator of a decimal is always one of the numbers 10, 100, 1000, etc., the necessity for writing the denominator, may be avoided by employing a point; thus, $\frac{3}{10}$ is written .3, and $\frac{14}{100}$ is written .14; the *mixed* number $3\frac{14}{100}$, consisting of a whole number and a fractional one, is written 3.14.

In setting down a decimal fraction the numerator must consist of as many places as there are ciphers in the denominator; and if it has not so many figures the defect must be supplied by placing ciphers before it; thus, $\frac{16}{100}$=.16, $\frac{16}{1000}$=.016, $\frac{16}{10000}$=.0016, etc. And as ciphers on the right-hand side of integers increase their value in a tenfold proportion, as 2, 20, 200, etc., so when set on the left hand of decimal fractions they decrease their value in a tenfold proportion, as .2, .02, .002, etc.; but ciphers set on the right hand of these fractions make no alteration in their value; thus, .2 is the same as .20 or .200.

The common arithmetical operations are performed the same way in decimals as they are in integers, regard being had only to the particular notation to distinguish the integral from the fractional part of a sum.

Addition of Decimals.—Addition of decimals is performed exactly like that of whole numbers, placing the numbers of the same denomination under each other, in which case the separating decimal points will range straight in one column.

Examples.

	Miles.	Feet.	Inches.
Add:	26.7	1.26	272.3267
	32.15	2.31	.0134
	143.206	1.785	2.1576
	.003	2.0	31.4
Sum:	202.059	7.355	305.8977

Subtraction of Decimals.—Subtraction of decimals is performed in the same manner as in whole numbers, observing to set the figures of the same denomination and the separating points directly under each other.

Examples.

From:	31.267	36.75	1.254	1364.2
Take:	2.63	.026	.316	25.163
Difference:	28.637	36.724	.938	1339.037

Multiplication of Decimals.—Multiply the numbers together as if they were whole numbers, and point off as many decimals from the right hand as there are decimals in both factors together; and when it happens that there are not so many figures in the product as there must be decimals, then prefix such number of ciphers to the left hand as will supply the defect.

Example I.

Multiply 3.25 by 4.5

	3.25
	4.5
	1625
	1300
Answer:	14.625

In one of the factors is one decimal, and in the other two; their sum, 3, is the number of decimals of the product.

Example II.

Multiply .17 by .06

	.17
	.06
Answer:	.0102

In each of the factors are two decimals; the product ought therefore to contain 4; and, there being only three figures in the product, a cipher must be prefixed.

EXAMPLE III.

Multiply 0.5 by 0.7

```
          0.5
          0.7
          ---
Answer:   0.35
```

EXAMPLE IV.

Multiply .18 by 24

```
          .18
           24
          ----
           72
          36
          ----
Answer:   4.32
```

DIVISION OF DECIMALS.—Division of decimals is performed in the same manner as in whole numbers. The number of decimals in the quotient must be equal to the excess of the number of decimals of the dividend above those of the divisor; when the divisor contains more decimals than the dividend, ciphers must be affixed to the right hand of the latter to make the number equal or exceed that of the divisor.

EXAMPLE I.

Divide 14.625 by 3.25

```
3.25)14.625(4.5
     13 00
     -----
      1625
      1625
```

In this example there are two decimals in the divisor and three in the dividend; hence, there is one decimal in the quotient.

EXAMPLE II.

Divide 3.1 by .0062

Previous to the division affix three ciphers to the right hand of 3.1, to make the number of decimals in the dividend equal the number in the divisor.

```
.0062) 3.1000 ( 500
       3 10
       ----
        000
```

EXAMPLE III.

Divide 17.256 by 1.16

```
1.16) 17.25600 ( 14.875+
      11 6
      ----
       565
       464
       ----
       1016
        928
        ----
         880
         812
         ---
          680
          580
          ---
          100
```

By pursuing the operation further the quotient may be carried out as many decimal places as desired.

MULTIPLICATION OF DECIMALS BY CONTRACTION.—The operation of multiplication of decimal fractions may be very much abbreviated when it is not required to retain any figures beyond a certain order or place; this will constantly occur in reducing the elements taken from the Nautical Almanac from Greenwich noon to later or earlier instants of time.

In multiplying by this method, omit writing down that part of the operation which involves decimal places below the required order, but mental note should be made of the product of the first discarded figure by the multiplying figure, and the proper number of tens should be carried over to insure accuracy in the lowest decimal place sought.

EXAMPLE: Required the reduction for the sun's declination for $7^h.43$, the hourly difference being $58''.18$, where the product is required to the second decimal.

By ordinary method.	*By contraction.*
$58''.18$	$58''.18$
$7^h.43$	$7^h.43$
17454	1.74
23272	23.27
40726	407.26
$432''.2774$	$432.''27$

In the contracted method, for the multiplier .03 it is not necessary to record the product of any figures in the multiplicand below units; for the multiplier .4, none below tenths; but in each case observe the product of the left-hand one of the rejected figures and carry forward the number of tens.

RULES AND PRINCIPLES OF MATHEMATICS.

Reduction of Decimals.—To reduce a vulgar fraction to a decimal, add any number of ciphers to the numerator and divide it by the denominator; the quotient will be the decimal fraction. The decimal point must be so placed that there may be as many figures to the right hand of it as there were added ciphers to the numerator. If there are not so many figures in the quotient place ciphers to the left hand to make up the number.

Example I.

Reduce $\frac{1}{50}$ to a decimal.

$$50)1.00$$

$$.02 \text{ Answer.}$$

Example II.

Reduce $\frac{3}{8}$ to a decimal.

$$8)3.000$$

$$.375 \text{ Answer.}$$

Example III.

Reduce 3 inches to the decimal of a foot.
Since 12 inches=1 foot this fraction is $\frac{3}{12}$.

$$12)3.00$$

$$.25 \text{ Answer.}$$

Example IV.

Reduce 15 minutes to the decimal of an hour.
Since $60^m = 1^h$, this fraction is $\frac{15}{60}$.

$$60)15.00$$

$$.25 \text{ Answer.}$$

Example V.

Reduce $17^m\ 22^s$ to the decimal of an hour.

$$22^s = \frac{22^m}{60} = 0^m.37.$$

$$17^m\ 37 = \frac{17^h.37}{60} = 0^h.289+ \text{Answer.}$$

Any decimal may be reduced to lower denominations of the same quantity by multiplying it by the number representing the relation between the respective denominations.

Example VI. Reduce 7.231 days to days, hours, minutes, and seconds.

$0^d.231$	$0^h.544$	$0^m.640$	
24	60	60	
924	$32^m.640$	$38^s.400$	Answer: $7^d\ 5^h\ 32^m\ 38^s.4$.
462			
$5^h.544$			

GEOMETRY.

Geometry is the science which treats of the description, properties, and relations of magnitudes, of which there are three kinds; viz, a *line*, which has only length without either breadth or thickness; a *surface*, comprehended by length and breadth; and a *solid*, which has length, breadth, and thickness.

A *point*, considered mathematically, has neither length, breadth, nor thickness; it denotes position simply.

A *line* has length without breadth or thickness.

A *surface* has length and breadth without thickness.

A *solid* has length, breadth, and thickness.

A *straight* or *right line* is the shortest distance between two points on a plane surface.

A *plane surface* is one in which, any two points being taken, the straight line between them lies wholly within that surface.

Parallel lines are such as are in the same plane and if extended indefinitely never meet.

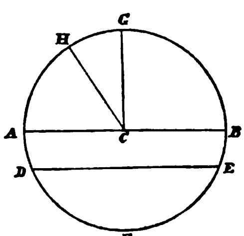


Fig. 82.

A *circle* is a plane figure bounded by a curved line of which every point is equally distant from a point within called the *center*. The bounding curve of the circle is called the *circumference*.

The *radius* of a circle, or *semidiameter*, is a right line drawn from the center to the circumference, as AC (fig. 82); its length is that distance which is taken between the points of the compasses to describe the circle.

A *diameter* of a circle is a right line drawn through the center and terminated at both ends by the circumference, as ACB, its length being twice that of the radius. A diameter divides the circle and its circumference into two equal parts.

An *arc* of a circle is any portion of the circumference, as DFE.

The *chord* of an arc is a straight line joining the ends of the arc. It divides the circle into two unequal parts, called *segments*, and is a chord to them both; thus, DE is the chord of the arcs DFE and DGE.

A *semicircle*, or half circle, is a figure contained between a diameter and the arc terminated by that diameter, as AGB or AFB.

Any part of a circle contained between two radii and an arc is called a *sector*, as GCH.

A *quadrant* is half a semicircle, or one-fourth part of a whole circle, as CAG.

All circles are supposed to have their circumferences divided into 360 equal parts, called degrees; each degree is divided into 60 equal parts, called minutes; and each minute into 60 equal parts, called seconds; an arc is measured by the number of degrees, minutes, and seconds that it contains.

A *sphere* is a solid bounded by a surface of which every point is equally distant from a point within, which, as in the circle, is called the *center*. Substituting *surface* for *circumference*, the definitions of the *radius* and *diameter*, as given for the circle, apply for the sphere.

An *angle* is the inclination of two intersecting lines, and is measured by the arc of a circle intercepted between the two lines that form the angle, the center of the circle being the point of intersection.

A *right angle* is one that is measured by a quadrant, or 90°. An *acute angle* is one which is less than a right angle. An *obtuse angle* is one which is greater than a right angle.

A *plane triangle* is a figure contained by three straight lines in the same plane.

When the three sides are equal, the triangle is called *equilateral;* when two of them are equal, it is called *isosceles.* When one of the angles is 90°, the triangle is said to be *right-angled.* When each angle is less than 90°, it is said to be *acute-angled.* When one is greater than 90°, it is said to be *obtuse-angled.* Triangles that are not right-angled are generally called *oblique-angled.*

A *quadrilateral* figure is one bounded by four sides. If the opposite sides are parallel, it is called a *parallelogram.* A parallelogram having all its sides equal and its angles right angles is called a *square.* When the angles are right angles and only the opposite sides equal, it is called a *rectangle.*

In a right-angled triangle the side opposite the right angle is called the *hypotenuse*, one of the other sides is called the *base*, and the third side is called the *perpendicular.* In any oblique-angled triangle, one side having been assumed as a base, the distance from the intersection of the other two sides to the base or the base extended, measured at right angles to the latter, is the perpendicular. In a parallelogram, one of the sides having been assumed as the base, the distance from its opposite side, measured at right angles to its direction, is the perpendicular. The term *altitude* is sometimes substituted for *perpendicular* in this sense.

Every section of a sphere made by a plane is a circle. A *great circle* of a sphere is a section of the surface made by a plane which passes through its center. A *small circle* is a section by a plane which intersects the sphere without passing through the center.

A great circle may be drawn through any two points on the surface of a sphere, and the arc of that circle lying between those points is shorter than any other distance between them that can be measured upon the surface. All great circles of a sphere have equal radii, and all bisect each other.

The extremities of that diameter of the sphere which is perpendicular to the plane of a circle are called the *poles* of that circle. In the case of a small circle the poles are named the *adjacent pole* and the *remote pole.* All circles of a sphere that are parallel have the same poles. All points in the circumference of a circle are equidistant from the poles. In the case of a great circle, the poles are 90° distant from every point of the circle.

Assuming any great circle as a *primary*, all great circles which pass through its poles are called its *secondaries.* All secondaries cut the primary at right angles.

USEFUL FORMULÆ DERIVED FROM GEOMETRY.—In these formulæ the following abbreviations are adopted:

b, base of triangle or parallelogram.
h, perpendicular of triangle or parallelogram.
l, height of cylinder or cone.
π, ratio of diameter to circumference (= 3.141593).
r, radius of sphere or circle.
d, diameter of sphere or circle.
A, major axis of ellipse.
a, minor axis of ellipse.
s, side of a cube.

Area of parallelogram $= b \times h$.
Area of triangle $= \frac{1}{2} b \times h$.
Area of any right-lined figure = sum of the areas of the triangles into which it is divided.
Sum of three angles of any triangle = 180°.
Circumference of circle $= 2\pi r$, or πd.
Area of circle $= \pi r^2$, or $\frac{\pi d^2}{4}$.
Angle subtended by arc equal to radius = 57°.29578.

Volume of sphere $= \frac{\pi d^3}{6}$.
Surface of sphere $= \pi d^2$, or $4\pi r^2$.
Area of ellipse $= \frac{\pi A a}{4}$.
Volume of cube $= s^3$.
Volume of cylinder = Area of base $\times\, l$.
Volume of pyramid or cone = Area of base $\times \frac{l}{3}$.

TRIGONOMETRIC FUNCTIONS.

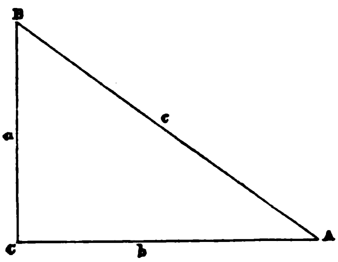


Fig. 83.

The *trigonometric functions* of the angle formed by any two lines are the *ratios* existing between the sides of a right triangle formed by letting fall a perpendicular from any point in one line upon the other line; no matter what point is chosen for the perpendicular nor which line, the ratios, and therefore the respective functions, will be the same for any given angle.

Let ABC (fig. 83) be a plane right triangle in which C is the right angle: A and B, the other angles; c, the hypotenuse; a and b the sides opposite the angles A and B, respectively. In considering the functions of the angle A, its opposite side, a, is regarded as the perpendicular, and its adjacent side, b, as the base; for the angle B, b is the perpendicular and a the base. Then the various ratios are designated as follows:

$\frac{a}{c}$, or $\frac{\text{perpendicular}}{\text{hypotenuse}}$, is called the *sine* of the angle A, abbreviated sin A;

$\frac{b}{c}$, or $\frac{\text{base}}{\text{hypotenuse}}$, is called the *cosine* of the angle A, abbreviated cos A;

$\frac{a}{b}$, or $\frac{\text{perpendicular}}{\text{base}}$, is called the *tangent* of the angle A, abbreviated tan A;

$\frac{b}{a}$, or $\frac{\text{base}}{\text{perpendicular}}$, is called the *cotangent* of the angle A, abbreviated cot A;

$\frac{c}{b}$, or $\frac{\text{hypotenuse}}{\text{base}}$, is called the *secant* of the angle A, abbreviated sec A;

$\frac{c}{a}$, or $\frac{\text{hypotenuse}}{\text{perpendicular}}$, is called the *cosecant* of the angle A, abbreviated cosec A;

1—cosine A, is called the *versed sine* of A, abbreviated vers A.

1—sine A, is called the *co-versed sine* of A, abbreviated covers A.

½ (1—cosine A) is called the haversine of A, abbreviated hav A.

The following relations may be seen to exist between the various functions:

$$\frac{1}{\sin A} = 1 \div \frac{a}{c} = \frac{c}{a} = \text{cosec } A;$$

$$\frac{1}{\cos A} = 1 \div \frac{b}{c} = \frac{c}{b} = \sec A;$$

$$\frac{1}{\tan A} = 1 \div \frac{a}{b} = \frac{b}{a} = \cot A;$$

$$\frac{\sin A}{\cos A} = \frac{a}{c} \div \frac{b}{c} = \frac{a}{b} = \tan A.$$

Hence the cosecant is the reciprocal of the sine, the secant is the reciprocal of the cosine, the cotan gent is the reciprocal of the tangent, and the tangent equals the sine divided by the cosine.

The *complement* of an angle is equal to 90° minus that angle, and thus in the triangle ABC the angle B is the complement of A. The *supplement* is equal to 180° minus the angle.

From the triangle ABC, regarding the angle B, we have:

$$\sin B = \frac{b}{c} = \cos A;$$

$$\tan B = \frac{b}{a} = \cot A;$$

$$\sec B = \frac{c}{a} = \text{cosec } A.$$

Hence it may be seen that the sine of an angle is the cosine of the complement of that angle; the tangent of an angle is the cotangent of its complement, and the secant of an angle is the cosecant of its complement.

The functions of angles vary in sign according to the quadrant in which the angles are located.

Let AA′ and BB′ (fig. 84) be two lines at right angles intersecting at the point O, and let that point be the center about which a radius revolves from an initial position OB, successively passing the points A, B′, A′. In considering the angle made by this radius at any position, P′, P″, P‴, P⁗, with the line OB, its position of origin, the functions will depend upon the ratios existing between the sides of a right triangle whose base, b, will always lie within BB′, and whose perpendicular, a, will always be parallel to AA′, while its hypotenuse, c (of a constant length equal to that of the radius), will depend upon the position occupied by the radius. Now, if OB and OA be regarded as the positive directions of the base and perpendicular, respectively, and OB′ and OA′ as their negative directions, the sign of the hypotenuse being always positive, the sign of any function may be determined by the signs of the sides of the triangle upon which it depends.

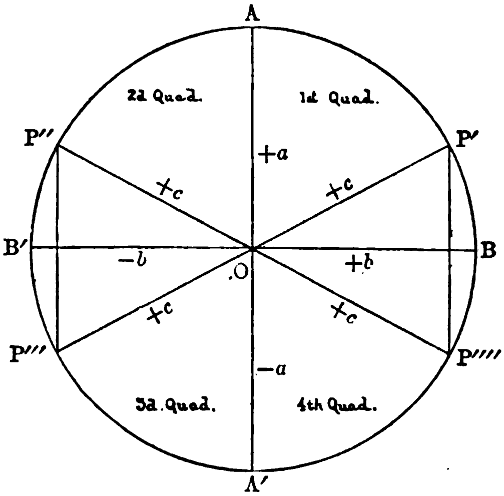


FIG. 84.

For example, the sine of the angle P″OB is $\frac{a}{c}$, and since a is positive the quantity has a positive value; its cosine is $\frac{b}{c}$, and as b is measured in a negative direction from O the cosine must therefore be negative.

In the first quadrant, between 0° and 90°, all quantities being positive, all functions will also be positive.

In the second quadrant, between 90° and 180°, sin A $\left(=\frac{a}{c}\right)$ is positive; cos A $\left(=\frac{b}{c}\right)$ has a negative value because b is negative; tan A $\left(=\frac{a}{b}\right)$ is also negative because of b. The cosecant, secant, and cotangent have, as in all cases, the same signs as the sine, cosine, and tangent, respectively, being the reciprocals of those quantities.

In the third quadrant, between 180° and 270°, sin A $\left(=\frac{a}{c}\right)$ and cos A $\left(=\frac{b}{c}\right)$ are both negative, because both a and b have negative values; tan A $\left(=\frac{a}{b}\right)$ is positive for the same reason.

In the fourth quadrant, between 270° and 360°, sin A $\left(=\frac{a}{c}\right)$ is negative, cos A $\left(=\frac{b}{c}\right)$ is positive, and tan A $\left(=\frac{a}{b}\right)$ is also negative.

From a consideration of the signs in the manner that has been indicated, the following relations will appear:

$$\sin A = \sin(180° - A) = -\sin(180° + A) = -\sin(360° - A) = -\sin(-A).$$
$$\cos A = -\cos(180° - A) = -\cos(180° + A) = \cos(360° - A) = \cos(-A).$$
$$\tan A = -\tan(180° - A) = \tan(180° + A) = -\tan(360° - A) = -\tan(-A).$$
$$\sin A = \cos(90° - A) = -\cos(90° + A) = -\cos(270° - A) = \cos(270° + A).$$

Any similar relation may be deduced from the figure.

It is of great importance to have careful regard for the signs of the functions in all trigonometrical solutions.

LOGARITHMS.

In order to abbreviate the tedious operations of multiplication and division with large numbers, a series of numbers, called *Logarithms*, was invented by Lord Napier, by means of which the operation of multiplication may be performed by addition, and that of division by subtraction. Numbers may be involved to any power by simple multiplication and the root of any power extracted by simple division.

In Table 42 are given the logarithms of all numbers, from 1 to 9999; to each one must be prefixed an index, with a period or dot to separate it from the other part, as in decimal fractions; the logarithms of the numbers from 1 to 100 are given in that table with their indices; but from 100 to 9999 the index is left out for the sake of brevity; it may be supplied, however, by the general rule that the index of the logarithm of any integer or mixed number is always one less than the number of integral places in the natural number. Thus, the index of the logarithm of any number (integral or mixed) between 10 and

100 is 1; from 100 to 1000 it is 2; from 1000 to 10000 it is 3, etc.; the method of finding the logarithms from this table will be evident from the rules that follow:

To find the logarithm of any number less than 100, enter the first page of the table, and opposite the given number will be found the logarithm with its index prefixed. Thus, opposite 71 is 1.85126, which is its logarithm.

To find the logarithm of any number between 100 and 1000, find the given number in the left-hand column of the table of logarithms, and immediately under 0 in the next column is a number, to which must be prefixed the number 2 as an index (because the number consists of three places of figures), and the required logarithm will be found. Thus, if the logarithm of 149 was required, this number being found in the left-hand column, against it, in the column marked 0 at the top (or bottom) is found 17319, prefixing to which the index 2, we have the logarithm of 149 = 2.17319.

To find the logarithm of any number between 1000 and 10000, find the three left-hand figures of the given number in the left-hand column of the table of logarithms, opposite to which, in the column that is marked at the top (or bottom) with the fourth figure, is to be found the required logarithm, to which must be prefixed the index 3, because the number contains 4 places of figures. Thus, if the logarithm of 1495 was required, opposite to 149, and in the column marked 5 at the top (or bottom) is 17464, to which prefix the index 3, and we have the logarithm, 3.17464.

To find the logarithm of any number above 10000, find the first three figures of the given number in the left-hand column of the table, and the fourth figure at the top or bottom, and take out the corresponding logarithm as in the preceding rule; take also the difference between this logarithm and the next greater, and multiply it by the remaining figure or figures of the number whose logarithm is sought, pointing off as many decimal places in the product as there are figures in the multiplier. To facilitate the calculation of the proportional parts several small tables are placed in the margin, which give the correction corresponding to the difference, and to the *fifth* figure of the proposed number. Thus, if the logarithm of 14957 was required, opposite to 149, and under 5, is 17464; the difference between this and the next greater number, 17493, is 29; this multiplied by 7 (the last figure of the given number) gives 203; pointing off the right-hand figure gives 20.3 (or 20) to be added to 17464, which makes 17484; to this, prefixing the index 4, we have the logarithm sought, 4.17484. This correction, 20, may also be found by inspection in the small table in the margin, marked at the top 29; opposite to the *fifth* figure of the number, 7, in the left-hand column, is the corresponding correction, 20, in the right-hand column.

Again, if the logarithm of 1495738 was required, the logarithm corresponding to 149 at the left, and 5 at the top, is, as in the last example, 17464; the difference between this and the next greater is 29; multiplying this by 738 (the given number excluding the first four figures) gives 21402; crossing off the three right-hand figures of this product (because the number 738 consists of three figures), we have the correction 21 to be added to 17464; and the index to be prefixed is 6, because the given number consists of 7 places of figures; therefore the required logarithm is 6.17485. This correction, 21, may be found as above, by means of the marginal table marked at the top 29, taking at the side 7.38 (or $7\frac{1}{3}$ nearly), to which corresponds 21, as before.

To find the logarithm of any mixed decimal number, find the logarithm of the number, as if it were an integer, by the preceding rules, to which prefix the index of the integral part of the given number. Thus, if the logarithm of the mixed decimal 149 5738 was required, find the logarithm of 1495738, without noticing the decimal point; this, in the last example, was found to be 17485; to this prefix the index 2, corresponding to the integral part 149; the logarithm sought will therefore be 2.17485.

To find the logarithm of any decimal fraction less than unity, it must be observed that the index of the logarithm of any number less than unity is negative; but, to avoid the mixture of positive and negative quantities, it is common to borrow 10 in the index, which, in most cases, may afterwards be neglected in summing them with other indices; thus, instead of writing the index − 1, it is written + 9; instead of − 2 we may write + 8; and so on. In this way we may find the logarithm of any decimal fraction by the following rule: Find the logarithm of a fraction as if it were a whole number; see how many ciphers precede the first figure of the decimal fraction, subtract that number from 9, and the remainder will be the index of the given fraction. Thus the logarithm of 0.0391 is 8.59218 − 10; the logarithm of 0.25 is 9.39794 − 10; the logarithm of 0.0000025 is 4.39794 − 10, etc. In most cases the writing of − 10 after the logarithm may be dispensed with, as it will be quite apparent whether the logarithm has a positive or a negative index.

To find the number corresponding to any logarithm, seek in the column marked 0 at top and bottom the next smallest logarithm, neglecting the index; write down the number in the side column abreast which this is found, and this will give the first three figures of the required number; follow the line until the logarithm next smaller than the given one is found, and the fourth figure of the required number will be at the top and bottom of the column in which this stands; take the difference between this next smaller logarithm and the next larger one in the table, and also the difference between the next smaller logarithm and the given one; entering the small marginal table which has for its heading the first-named difference, and finding in the right-hand column of that table the last-named difference, there will appear abreast the latter, in the left-hand column, the fifth figure of the required number. Where it is desired to determine figures beyond the fifth for the corresponding number, the difference between the next lower logarithm and the given one may be divided by the difference between the next lower and next higher ones, and the quotient (disregarding the decimal point, but retaining any ciphers that may come between the decimal point and the significant figures) will be the fifth and succeeding figures of the number sought. Having found the figures of the corresponding number, point off from the left a number of figures which shall be one greater than the index number, and there place a decimal point. In this operation of placing the decimal point, proper account must be taken of the negative value of any index.

Thus, if the number corresponding to the logarithm 1.52634 were required, find 52634 in the column marked 0 at the top or bottom, and opposite to it is 336; now, the index being 1, the required number must consist of two integral places; therefore it is 33.6.

If the number corresponding to the logarithm 2.57345 were required, look in the column 0 and find in it, against the number 374, the logarithm 57287, and, guiding the eye along that line, find the given logarithm, 57345, in the column marked 5; therefore thè mixed number sought is 3745, and since the index is 2, the integral part must consist of 3 places; therefore the number sought is 374.5. If the index be 1 the number will be 37.45, and if the index be 0 the number will be 3.745. If the index be 8, corresponding to a number less than unity, the number will be 0.03745.

Again, if the number corresponding to the logarithm 3.57811 were required, find, against 378 and under 5, the logarithm 57807, the difference between this and the next greater logarithm, 57818, being 11, and the difference between 57807 and the given logarithm, 57811, being 4; in the marginal table headed 11, find in the right-hand column the number 4, and abreast the latter appears the figure 4, which is the fifth figure of the required number; hence the figures are 37854; pointing off from the left $3 + 1 = 4$ places, the number is 3785.4.

If the given logarithm were 5.57811, since the index 5 requires that there shall be six places in the whole number, it is desirable to seek accuracy to the sixth figure. The logarithmic part being the same as in the example immediately preceding, it is found as before that the first four figures are 3785, the difference between the next lower and next greater logarithms is 11, and between the next lower logarithm and the given one is 4; divide 4 by 11 and the quotient is .36; drop the decimal point, annex and point off, and the number required is found to be 378536.

It may be remarked that in using five-place logarithm tables it is not generally to be expected that results will be exact beyond the fifth figure.

To show, at one view, the indices corresponding to mixed and decimal numbers, the following examples are given:

Mixed number.	*Logarithms.*	*Decimal number.*	*Logarithms.*
40943. 0	Log. 4. 61218	0. 40943	Log. 9. 61218—10
4094. 8	Log. 3. 61218	0. 040943	Log. 8. 61218—10
409. 43	Log. 2. 61218	0. 0040943	Log. 7. 61218—10
40. 943	Log. 1. 61218	0. 00040943	Log. 6. 61218—10
4. 0943	Log. 0. 61218	0. 000040943	Log. 5. 61218—10

To perform multiplication by logarithms, add the logarithms of the two numbers to be multiplied and the sum will be the logarithm of their product.

EXAMPLE I.

Multiply 25 by 35.

25	Log. 1. 39794
35	Log. 1. 54407
Product, 875	Log. 2. 94201

EXAMPLE II.

Multiply 22.4 by 1.8.

22. 4	Log. 1. 35025
1. 8	Log. 0. 25527
Product, 40. 32	Log. 1. 60552

EXAMPLE III.

Multiply 3.26 by 0.0025.

3. 26	Log. 0. 51322
0. 0025	Log. 7. 39794
Product, 0. 00815	Log. 7. 91116

EXAMPLE IV.

Multiply 0.25 by 0.003.

0. 25	Log. 9. 39794
0. 003	Log. 7. 47712
Product, 0. 00075	Log. 6. 87506

In the last example, the sum of the two logarithms is really 16.87506—20; this is the same as 6.87506—10, or, remembering that the quantity is less than unity, simply 6.87506.

To perform division by logarithms, from the logarithm of the dividend subtract the logarithm of the divisor; the remainder will be the logarithm of the quotient.

EXAMPLE I.

Divide 875 by 25.

875	Log. 2. 94201
25	Log. 1. 39794
Quotient, 35	Log. 1. 54407

EXAMPLE II.

Divide 40.32 by 22.4.

40. 32	Log. 1. 60552
22. 4	Log. 1. 35025
Quotient, 1. 8	Log. 0. 25527

EXAMPLE III.

Divide 0.00815 by 0.0025.

0. 00815	Log. 7. 91116
0. 0025	Log. 7. 39794
Quotient, 3. 26	Log. 0. 51322

EXAMPLE IV.

Divide 0.00075 by 0.025.

0. 00075	Log. 6. 87506
0. 025	Log. 8. 39794
Quotient, 0. 03	Log. 8. 47712

In Example III both the divisor and dividend are fractions less than unity, and the divisor is the lesser; consequently the quotient is greater than unity. In Example IV both fractions are less than unity; and, since the divisor is the greater, its logarithm is greater than that of the dividend; for this reason it is necessary to borrow 10 in the index before making the subtraction, that is, to regard the logarithm of .00075 as 16.87506 — 20; hence the quotient is less than unity.

The *arithmetical complement* of the logarithm of a number, usually called the *cologarithm* of the number, and denoted by colog, is the remainder obtained by subtracting the logarithm of the number from the logarithm of unity. It is therefore the logarithm of the reciprocal of the number; and, since the effect of dividing by any number is the same as that of multiplying by its reciprocal, it follows that, in performing division by logarithms, we may either subtract the logarithm of the divisor or add the arithmetical complement of that logarithm. As the addition of a number of quantities can be performed in a single operation, while in subtraction the difference between only two quantities can be taken at a time, it is frequently a convenience to deal with the arithmetical complements rather than with the logarithms themselves.

EXAMPLE I.

Divide 875 by 25.

875........................Log. 2.94201
25 ......Log. 1.39794....Colog. 8.60206

Quotient, 35........................Log. 1.54407

EXAMPLE II.

Divide 0.00075 by 0.025.

0.00075..................Log. 6.87506
0.025....Log. 8.39794....Colog. 1.60206

Quotient, 0.03....................Log. 8.47712

EXAMPLE III.

Simplify the expression, $\frac{40.32\times.00815}{22.4\times.0025}$.

40.32 ....Log. 1.60552
.00815 ....Log. 7.91116
22.4........Log. 1.35025....Colog. 8.64975
.0025......Log. 7.39794....Colog. 2.60206

Result, 5.868 ....Log. 0.76849

To perform involution by logarithms, multiply the logarithm of the given number by the index of the power to which the quantity is to be raised; the product will be the logarithm of the power sought.

EXAMPLE I.

Required the square of 18.

18..........................Log. 1.25527
2

Answer, 324........................Log. 2.51054

EXAMPLE II.

Required the square of 6.4.

6.4 ....Log. 0.80618
2

Answer, 40.96 ....Log. 1.61236

EXAMPLE III.

Required the cube of 13.

13..........................Log. 1.11394
3

Answer, 2197........................Log. 3.34182

EXAMPLE IV.

Required the cube of 0.25.

0.25 ....Log. 9.39794
3

Answer, 0.015625..................Log. 8.19382

In the last example, the full product of the multiplication of 9.39794—10 by 3 is 28.19382—30, which is equivalent to 8.19382—10.

To perform evolution by logarithms divide the logarithm of the number by the index of the power; the quotient will be the logarithm of the root sought. If the number whose root is to be extracted is a decimal fraction less than unity, increase the index of its logarithm by adding a number of tens which shall be less by one than the index of the power before making the division.

EXAMPLE I.

Required the square root of 324.

324......................Log. 2)2.51055

Answer. 18......................Log. 1.25527

EXAMPLE II.

Required the cube root of 2197.

2197......................Log. 3)3.34183

Answer, 13......................Log. 1.11394

EXAMPLE III.

Required the square root of 40.96.

40.96......................Log. 2)1.61236

Answer, 6.4 ....Log. 0.80618

EXAMPLE IV.

Required the cube root of 0.015625.

0.015625..................Log. 8.19382
Add 20 to the index .... 3)28.19382

Answer, 0.25 ....Log. 9.39794

In the last example the logarithm 8.19382—10 was converted into its equivalent form of 28.19382—30, which, divided by 3, gives 9.39794—10.

To find the logarithm of any function of an angle, Table 44 must be employed. This table is so arranged that on every page there appear the logarithms of all the functions of a certain angle A, together with those of the angles 90°−A, 90°+A, and 180°−A; thus on each page may be found the logarithms of the functions of four different angles. The number of degrees in the respective angles are printed in bold-faced type, one in each corner of the page; the number of minutes corresponding appear in one column at the left of the page and in another at the right; the names of the functions to which the various logarithms correspond are printed at the top and bottom of the columns. The invariable rule must be to take the name of the function from the top or the bottom of the page, according as the number of degrees of the given angle is found at the top or bottom; and to take the minutes from the right or left hand column, according as the number of degrees is found at the right or left hand side of the page; or, more briefly, take names of functions and number of minutes, respectively, from the line and column nearest in position to the number of degrees.

Taking, as an example, the thirty-first page of the table, it will be found that 30° appears at the upper left-hand corner, 149° at the upper right-hand, 59° at the lower right-hand, and 120° at the lower left-hand corner. Suppose that it is desired to find the log. sine of 30° 10′; following the rule given, we find 10′ in the left-hand column and Sine at the top of the page, and abreast one and below the other is the required logarithm, 9.70115. But if the log. sine of 59° 10′ were sought, as 59° appears below and at the right of the page, the logarithm 9.93382 would be taken from the column marked Sine at the bottom and abreast 10′ on the right. It may also be seen that log. sin 30° 10′=log. cos 59° 50′=log. cos 120° 10′=log. sin 149° 50′=9.70115, the equality of the functions agreeing with trigonometrical deductions; (in this statement numerical values only are regarded, and not signs; the latter must, of course, be taken into account in all operations).

EXAMPLE I.

Required the log. sine, cosecant, tangent, cotangent, secant, and cosine of 28° 37′.

Log. sin	9.68029	Log. cot	10.26313
Log. cosec	10.31971	Log. sec	10.05658
Log. tan	9.73687	Log. cos	9.94342

EXAMPLE II.

Required the log. sine, cosecant, tangent, cotangent, secant, and cosine of 75° 42′.

Log. sin	9.98633	Log. cot	9.40636
Log. cosec	10.01367	Log. sec	10.60730
Log. tan	10.59364	Log. cos	9.39270

When the angle of which the logarithmic function is required is given to seconds, it becomes necessary to interpolate between the logarithms given for the even minutes next below and next above; this may be done either by computation or (except in a few cases) by inspection of the table.

To interpolate by computation, let n represent the number of seconds, D the difference between the logarithms of the next lesser and next greater even minute, and d the difference between the logarithm of the next lesser even minute and that of the required angle. Then,

$$d=\frac{n}{60}\times \text{D}.$$

It should be noted when the number of seconds is 30, 20, 15, or some similar number, permitting the reduction of the fraction $\frac{n}{60}$ to a simple value, such as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, as the interpolation by this method may thus be made with greater facility.

Having obtained the difference of the logarithm from that of the next lower even minute, it must be applied in the proper direction—that is, if the function is such that its logarithm increases as the angle increases, the logarithmic difference must be added; but if it decreases, then that difference must be subtracted.

For example, let it be required to find the log. sin and log. cosec of 30° 10′ 19″. The log. sin of 30° 10′ is 9.70115; the difference between this logarithm and that of the sine of 30° 11′ (9.70137) is + 22, which is D. Hence,

$$d=\frac{19}{60}\times(+22)=+7;$$

and the required logarithm is 9.70122. The log. cosec of 30° 10′ is 10.29885; the difference, D, between that and log. cosec 30° 11′ (10.29863) is −22. In this case

$$d=\frac{19}{60}\times(-22)=-7;$$

therefore, log. cosec 30° 10′ 19″=10.29878.

The method of interpolating by inspection consists in entering that column marked "Diff." which is adjacent to the one from which the logarithmic function for the next lower minute is taken, and finding, abreast the number in the left-hand minute column which corresponds to the seconds, the required logarithmic difference; and the latter is to be added or subtracted according as the logarithms increase or decrease with an increased angle. Thus, if it be required to find log. sin 30° 10′ 19″, find as before log. sin 30° 10′=9.70115, then, in the adjacent column headed "Diff." and abreast the number of seconds, 19, in the left-hand minute column will be found 7, the logarithmic difference; add this, as the function is increasing, and we have the required logarithm 9.70122. If log. cosec 30° 10′ 19″ be sought, find log. cosec 30° 10′=10.29885; then in the adjacent difference column, which is the same as was used for the sines, find as before the logarithmic difference, 7; and since this function decreases as the angle increases, this must be subtracted; therefore, log. cosec 30° 10′ 19″=10.29878.

This method of interpolation by inspection is not available in that portion of the table where the logarithmic differences vary so rapidly that no values will apply alike to all the angles on the same page; on such pages the difference for one minute is given in a column headed "Diff. 1′," instead of the usual difference for each second; in this case the interpolation must be made by computation, the given difference for one minute being D. In other parts of the table the interpolation by inspection may be liable to slight error because of the variation in logarithmic difference for different angles on the same page; but the tabulated values are sufficiently accurate for the usual calculations in navigation.

It will be evident that while the methods explained have contemplated entering the tables with a smailer angle and interpolating *ahead*, it would be equally correct to enter with a greater angle and nterpolate *back* for the proper number of minutes, making the requisite change in the sign of the icorrection.

EXAMPLE I.

Required the log. sine, cosine, and tangent of 42° 57′ 06″.

	For 42° 57′	d	For 42° 57′ 06″.
Log. sin	9.83338	+1	9.83339
Log. cos	9.86448	−1	9.86447
Log. tan	9.96890	+3	9.96893

EXAMPLE II.

Required the log. secant, cosecant, and cotangent of 175° 32′ 36″.

	For 175° 32′	d	For 175° 32′ 36″
Log. sec	10.00132	− 1	10.00131
Log. cosec	11.10858	+97	11.10955
Log. cot	11.10726	+98	11.10824

It should be observed that, for uniformity and convenience, all logarithms given in Table 44 have been increased by 10 in the index, and it is understood that −10 ought properly to be written after each; thus all logarithms under 10.00000 represent functions whose value is less than unity, and all over 10.00000 those greater than unity; for example, 11.10726 is the logarithm of a number in which the decimal point should be placed after the second figure from the left.

To find the angle corresponding to any logarithmic function, the process is the reverse of the one just described. Find, in the column marked with the name of the function, either at top or bottom, the two logarithms between which the given one falls; write down the degrees and minutes of the lesser of the two corresponding angles, which will be the degrees and minutes of the angle required. Call the difference between the two tabulated logarithms D, and the difference between the given logarithm and that which corresponds to the lesser angle, *d;* then if *n* represents the number of seconds, we have:

$$n = \frac{d}{D} \times 60.$$

Or, the same may be obtained by inspection (except where, as before explained, the differences for seconds are not tabulated) by finding, in the "Diff." column adjacent to that from which the logarithm was taken, the logarithmic difference, *d*, and noting the number of seconds abreast which it stands in the left-hand minute column.

Interpolation may be also made in the reverse direction from the next greater even minute.

Thus, if it be required to find the angle corresponding to log. sin 9.61400, we find log. sin 24° 16′, 9.61382, and log. sin 24° 17′, 9.61411; hence D=29, and *d*=18;

$$n = \frac{18}{29} \times 60 = 37;$$

and the angle is 24° 16′ 37″. Or, in adjacent column headed "Diff.," 18 would be found abreast 38, 39, or 40 (seconds) in the left-hand minute column—a correspondence sufficiently close for navigation work.

If the angle were known to be in the second quadrant, we find log. sin 155° 43′, 9.61411, and log. sin 155° 44′, 9.61382; here D=29, and *d*=11;

$$n = \frac{11}{29} \times 60 = 23;$$

therefore, the angle is 155° 43′ 23″. Or, in adjacent "Diff." column find, abreast 11, 23 or 24 seconds.

EXAMPLE I.

Find angles less than 90° corresponding to log. cot 10.33621, log. sec 10.11579, and log. cos 8.70542.

		°	′	d	″
Log. cot	10.33621	24	45	8	15
Log. sec	10.11579	40	00	4	22
Log. cos	8.70542	87	05	116	28

EXAMPLE II.

Find angles in second quadrant corresponding to log. tan 10.15593, log. sin 8.87926, and log. cosec 10.04944.

		°	′	d	″
Log. tan	10.15593	124	55	19	42
Log. sin	8.87926	175	39	69	25
Log. cosec	10.04944	116	49	3	27

The Hour Columns in Table 44 give the measure in time corresponding to twice the angular distance given in arc. Thus, abreast the angle 13° 00′ stands in the P. M. column $1^h\ 44^m\ 00^s$, corresponding in time to 2×13° 00′; and in the A. M. column $10^h\ 16^m\ 00^s$, which is the same subtracted from 12^h. These columns are of use in working the various formulæ which involve functions of half the hour angle. Interpolation for values intermediate to those given in the tables is made on the same principle as for the angular measure; this operation may be performed by inspection by the use of the small tables at the bottom of each page, where *n*, the number of seconds of time, is given in bold-faced type, and *d*, the logarithmic difference for the respective columns, appears below.

EXAMPLE I.

Given $t = 1^h\ 48^m\ 44^s$, find log. cot ½ *t*.

For $1^h\ 48^m\ 40^s$,	log. cot. ½ *t*	10.61687
Diff. for 4^s, Col. B	−	28
For $1^h\ 48^m\ 44^s$,	log. cot ½ *t*	10.61659

EXAMPLE II.

Given log. sin ½ *t*, 9.91394, find the Hour A. M. corresponding.

For 9.91389,	$4^h\ 39^m\ 12^s$
Diff. for 5, Col. C	- 5
For 9.91394,	4 39 07

MISCELLANEOUS USEFUL DATA.

Earth's Polar radius=6,356,583.8 meters.
Earth's Equatorial radius=6,378,206.4 meters.

Earth's Compression$=\frac{1}{293.465}$.

Earth's Eccentricity=0.0822719 ....log 8. 9152513.
Number of feet in one statute mile=5280...............log 3. 7226339.
Number of feet in one nautical mile=6080.27..........log 3. 7839229.
Sine of 1″=0.00000485.................................log 4. 6855749.
Sine of 1′=0.00029089.................................log 6. 4637261.
The Napierian base e=2.7182818 ....log 0. 4342945.
The modulus of common logarithms=0.4342945 ....log 9. 6377843.
French meter in English feet, 3.2808333 ....log 0. 5159842.
French meter in English statute miles, 0.000621370 ....log 6. 7933503.
French meter in nautical miles, 0.000539568............log 6. 7320613.
1 pound Avoirdupois=7,000 grains Troy.
French gramme=0.00220606 Imperial pound Troy.
French kilogramme=0.0196969 English cwts.

Cubic inch of distilled water, in grains=252.458.
Cubic foot of water, in ounces Troy=908.8488.
Cubic foot of water, in pounds Troy=75.7374.
Cubic foot of water, in ounces Avoirdupois=997.1369691.
Cubic foot of water, in pounds Avoirdupois=62.3210606.
} Bar. 30.00 in.; ther. 62° F.

Length of pendulum which vibrates second at Greenwich, 39.1393 inches.

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

The following table contains the latitude and longitude of a large number of places, together with lunitidal intervals and tidal ranges at the more important ones. It is arranged geographically and followed by an alphabetical index.

The geographical position generally relates to some specified exact location, and is based upon the best available authority. The tidal data relate to the waters adjacent to the point whose latitude and longitude are given, being abstracted from the Tide Tables published by the United States Coast and Geodetic Survey.

The high-water and low-water lunitidal intervals represent the mean intervals between the moon's transit and the time of next succeeding high and low waters throughout a lunar month. The spring and neap ranges are the differences in height between high water and low water at spring and at neap tides. For those places where the tide is chiefly of a diurnal type, and where there is usually but one high and one low water during a lunar day, the tidal values are bracketed; in such cases the lunitidal intervals are for the semidiurnal part of the tide (which, however, is only appreciable for a few days when the moon is near the equator), and the range given in the column headed "Spg." does not, as in other cases, apply to the spring tide, but to the greatest periodic daily range, which usually occurs a day or two after the moon attains its extreme of declination, and is therefore near one of the tropics. As those places where the diurnal type predominates seldom experience large tidal effects, the general data furnished regarding such tides will suffice for the ordinary purpose of the navigator. The method of finding the time of high or low water from this table is illustrated in article 504, Chapter XX.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Labrador.	Salisbury Island: E. pt.	63 27 00	76 30 00				
	Nottingham Island: S. pt.	63 06 00	77 50 00	8 58	2 46	13. 5	6. 1
	Digges Island: W. extreme	62 37 00	78 08 00				
	Cape Wostenholme	62 35 00	77 33 00				
	Charles Island: E. pt.	62 48 00	74 00 00				
	W. pt.	62 50 00	75 20 00				
	Cape Weggs	62 30 00	74 03 00				
	Prince of Wales Sound: Center of ent.	62 07 00	72 25 00				
	Cape of Hopes Advance	61 18 00	70 02 00				
	Akpatok Island: E. pt.	60 10 00	67 05 00				
	Green Island: NE. pt.	60 40 00	67 50 00				
	Button Islands: N. pt.	60 52 00	64 40 00				
	Cape Chidleigh	60 33 00	64 12 00				
	Resolution Island: S. pt., Hutton h'dl'd.	61 21 00	65 00 00				
	E. pt., C. Resolution.	61 40 00	64 30 00				
	Black Head	60 00 00	64 28 00				
	Eclipse Harbor: E. side	59 48 00	64 07 15	8 00	1 48	5. 0	2. 0
	Nachvack Bay: Islands off entrance	59 07 00	63 20 00	7 00	0 48	5. 2	2. 1
	Saddle Island	57 35 00	61 20 00				
	Port Manvers: Entrance	57 00 00	62 07 00				
	Nain: Church	56 32 45	61 40 13	7 00	0 48	6. 5	3. 0
	Hopedale Harbor: Hill to E'd	55 27 04	60 12 34	5 30	11 43	6. 9	3. 2
	Aillick Harbor: Cape Mokkivik	55 13 33	59 08 01				
	Cape Harrison: N. extreme	54 55 50	57 56 40				
	Indian Harbor: Obsy	54 26 55	57 12 40	6 10	12 23	7. 0	3. 2
	Outer Gannet Island: Summit	54 00 05	56 31 31				
	Gready Harbor	53 50 00	56 23 00				
	Cartwright Harbor: Caribou Castle	53 42 37	56 59 50				
	Indian Tickle: Summit	53 34 25	55 58 39	6 27	0 15	6. 0	2. 8
	Roundhill Island: Summit	53 26 00	55 35 48				
	Occasional Harbor: E. summit of Twin I.	52 40 07	55 44 29	6 38	0 26	5. 0	2. 3
	Cape St. Lewis: SE. pt.	52 21 16	55 38 08	6 30	0 18	3. 5	1. 6
	Battle Islands: NE. extreme, SE. I.	52 15 36	55 32 20				
	Table Head	52 06 00	55 41 00				
	Belle Isle: Lighthouse	51 53 00	55 22 10				
Newfoundland.	Cape Bauld: Lighthouse	51 38 48	55 25 12				
	Bell Island: S. end	50 42 10	55 35 30				
	Cape St. John: Gull Island light.	49 59 54	55 21 33				
	Tilt Cove, Union Copper Mine	49 53 00	55 37 17				
	Funk Island: Summit	49 45 29	53 10 56				
	Offer Wadham: Lighthouse	49 35 40	53 45 00				
	Toulinguet Islands: Lighthouse	49 41 20	54 47 35				
	Seldom-come-by Harbor: Ship Hill	49 36 50	54 12 00				
	Cape Freels: Gull I.	49 15 20	53 25 12				
	Greenspond Island	49 04 20	53 37 45				
	Cape Bonavista: Lighthouse	48 42 01	53 04 42				
	Catalina Harbor: Green I. lighthouse	48 30 15	53 02 40				
	Bonaventure Head	48 16 55	53 23 35				
	Hearts Content: Lighthouse	47 53 10	53 23 20	7 23	1 11	4. 1	1. 9
	Baccalieu Island: Lighthouse	48 08 58	52 47 42				
	Harbor Grace: Lighthouse on beach	47 42 45	53 08 11	7 15	1 03	3. 3	1. 5
	Cape St. Francis: Lighthouse	47 48 30	52 47 20				
	St. Johns Harbor: Chain Rock Battery	47 34 02	52 40 54	7 12	1 01	3. 3	1. 5
	Cape Race: Lighthouse	46 39 24	53 04 30	6 50	0 38	6. 5	3. 0
	Cape Pine: Lighthouse	46 37 04	53 31 55				
	Trepassey Harbor: Shingle Neck	46 43 20	53 22 10	6 50	0 38	6. 6	3. 1
	Cape St. Mary: Lighthouse	46 49 34	54 11 42	8 20	2 08	7. 2	3. 3
	Little Placentia Harbor: W. side Coopers Cove	47 17 55	53 58 43				
	Burin Island: Lighthouse	47 00 26	55 08 49				
	Laun: Gr. Laun R. C. Church	46 56 30	55 32 00	8 05	1 53	7. 0	3. 2

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Newfoundland.	St. Pierre: U. S. Coast Survey Station	46 46 51	56 10 36	8 23	2 11	6.6	3.1
	Brunet Island: Mercers Hd. lighthouse	47 15 30	55 51 40	8 53	2 41	6.5	3.0
	Boar Islands: Burgeo I. lighthouse	47 35 13	57 36 52	8 22	2 10	6.2	2.9
	La Poile Bay: Gr. Espic Church	47 39 50	58 24 10	8 50	2 38	6.0	2.8
	Cape Ray: Lighthouse	47 37 00	59 18 00				
	Codroy Island: S. side Boat Harbor	47 52 30	59 23 40	8 50	2 32	4.3	2.1
	Cape St. George: Red I., SE. pt	48 33 48	59 13 10				
	Cow Head: NW. extreme	49 55 20	57 50 00	9 40	3 13	4.9	2.5
	Port Saunders: Two Hills Pt	50 38 30	57 17 07				
	Rich Point: Lighthouse	50 41 50	57 25 00				
	Férolle Pena: New Férolle Pt	51 02 00	57 03 50				
	Flower Cove: Capstan Pt	51 17 25	56 44 45				
	Green Island: 150 fms. from NE. end	51 24 10	56 33 40				
	Cape Norman: Lighthouse	51 38 00	55 53 52				
Labrador.	Chateau Bay: S. pt. Castle I	51 58 00	55 50 20				
	Amour Point: Lighthouse	51 27 35	56 51 05				
	Wood Island: S. pt	51 22 45	57 08 00				
	Greenly Island: Lighthouse	51 22 26	57 10 04				
	Bradore Bay: Obs. Spot, Jones Pt	51 27 22	57 13 21				
	Old Fort Island: Center	51 21 40	57 46 00				
	Great Mekattina Island: SE. pt	50 47 30	58 51 30				
	Mekattina Harbor: S. point of Dead Cove.	50 46 44	58 59 20				
	Little Mekattina I.: S. pt. C. McKinnon.	50 31 10	59 20 25				
	St. Mary Reefs	50 14 00	59 45 00				
	South Makers Ledge	50 09 30	59 57 00				
R. and G. of St. Lawrence.	Cape Whittle	50 11 00	60 08 00				
	Natashquan Point: S. edge	50 06 00	61 44 00	1 25	6 45	4.0	2.0
	Clearwater Point: SW. extreme	50 12 27	63 27 03				
	Carousel Island: Lighthouse	50 05 40	66 22 44	1 43	7 05	8.1	6.0
	Point de Monts: Lighthouse	49 19 35	67 21 55	1 48	7 18	10.8	8.0
	Quebec: Mann's Bastion, Citadel	46 48 23	71 12 19	6 07	0 54	14.6	10.8
	Quebec: Bonner's Hill Obsy	46 47 59	71 13 10				
	Montreal: St. James Cathedral	45 29 57	73 34 08				
	Ottawa: Dominion Observatory	45 23 30	75 42 59				
	Father Point: Lighthouse	48 31 25	68 27 40	1 52	7 33	12.0	8.9
	Cape Chatte: Extreme	49 06 00	66 46 00	1 46	7 13	10.5	7.8
	Cape Magdalen: Lighthouse	49 15 40	65 19 30	1 33	6 50	6.4	4.7
	Cape Rosier: Lighthouse	48 51 37	64 12 00	1 25	6 40	5.5	4.1
	Cape Gaspé: Lighthouse	48 45 15	64 09 35				
	Anticosti Island: Heath Pt. lighthouse	49 05 20	61 42 30	1 20	6 35	3.6	1.8
	SW. pt. lighthouse	49 23 45	63 35 46	1 25	6 40	4.9	2.5
New Brunswick.	Bonaventure Island: E. pt	48 29 30	64 08 00				
	Leander Shoal	48 24 00	64 18 00				
	Macquereau Point	48 12 00	64 46 30	1 55	7 33	4.7	2.3
	Chaleur Bay: Carlisle	48 01 00	65 19 00	2 20	8 07	4.8	2.4
	Dalhousie I	48 04 24	66 22 10	3 10	9 10	8.1	4.1
	Miscou Island: Birch Pt. lighthouse	48 01 07	64 29 20	2 00	8 25	4.0	2.0
	Miramichi Bay: Portage I., N. pt	47 14 00	65 02 00	4 16	10 59	2.3	1.2
	Point Escumenac: Lighthouse	47 05 00	64 47 33				
P. Edward I.	North Point: Lighthouse	47 03 46	63 58 49	4 20	11 00	2.4	1.2
	Malpeque Bay: Royalty Pt	46 33 56	63 41 35	5 15	11 55	1.8	0.9
	East Point: Lighthouse	46 27 15	61 57 35	8 17	2 20	1.4	0.7
	Charlottetown: Blackhouse Pt. light	46 11 36	63 06 58	11 07	4 23	6.4	3.2
Magdalen Is.	Gt. Bird Rock: Lighthouse	47 50 40	61 08 32				
	East Island: E. extreme	47 37 40	61 24 30				
	Entry Island: Lighthouse	47 16 30	61 41 20				
	Amherst Hbr.: N. side of entrance	47 14 23	61 49 38				
	Deadman Rock: W. pt	47 16 03	62 12 25				

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	St. Paul Island: Lighthouse, NE. end	47 13 50	60 08 32	8 30	2 12	2.7	1.4
	Lighthouse, SW. end	47 11 20	60 09 50				
C. Breton I.	Cape North: Lighthouse	47 01 45	60 23 27	8 35	2 17	3.1	1.6
	St. Anns Harbor: E. pt. entrance	46 21 00	60 27 00	8 25	2 13	6.0	3.7
	Sydney Harbor: Lighthouse	46 12 25	60 12 50	8 10	2 05	5.0	3.1
	Scatari Island: Lighthouse, NE. pt	46 02 15	59 40 25				
	Louisburg: Lighthouse, NE. pt	45 54 34	59 59 26	7 45	1 35	5.0	3.1
	Madame Island: S. pt	45 28 00	61 03 00	7 55	1 47	5.0	3.1
	Port Hood: Just-au-corps I	46 00 00	61 36 00	9 05	2 47	3.5	1.8
	Sable Island: Lighthouse, E. end	43 58 14	59 44 15				
Nova Scotia.	Pictou: Customhouse	45 40 50	62 42 10	9 34	3 13	3.9	2.0
	Cape St. George	45 52 00	61 52 00	9 20	3 00	2.8	1.4
	North Canso: Lighthouse, NW. entrance	45 41 42	61 29 10	9 26	3 10	3.1	1.6
	Arichat Harbor: R. C. Church steeple	45 30 48	61 01 47	7 55	1 47	5.0	3.1
	Cape Canso: Cranberry I., lighthouse	45 19 49	60 55 41	7 43	1 36	6.5	4.0
	White Head Island: Lighthouse	45 11 58	61 08 14	7 45	1 38	6.6	4.1
	Green Island: Lighthouse	45 06 15	61 32 40				
	Wedge Island: Lighthouse	45 00 35	61 52 45				
	Halifax: Dockyard observatory	44 39 38	63 35 22	7 34	1 46	5.2	3.2
	Sambro Island: Lighthouse	44 26 10	63 33 30				
	Margaret Bay: Shut-in I	44 34 00	63 54 00	7 32	1 30	7.1	4.4
	Tancook Island	44 29 00	64 06 00				
	Lunenburg: Battery Pt. light	44 21 45	64 17 35	7 39	1 36	7.0	4.3
	Cape La Have: Black Rock	44 12 00	64 18 00				
	Coffin Island: Lighthouse	44 02 00	64 37 30				
	Little Hope Island: Lighthouse	43 48 30	64 47 15				
	Shelburne Hbr.: Two lights, McNutts I.	43 37 15	65 15 45				
	Cape Sable: Lighthouse	43 23 19	65 37 11	8 17	2 05	8.5	5.2
	Seal Island: Lighthouse	43 23 34	66 00 52	9 35	3 23	12.8	9.5
	Yarmouth: Cape Fourchu light	43 47 28	66 09 21	10 00	3 41	16.0	11.8
	Cape St. Mary	44 05 20	66 12 40				
	Bryer Island: Lighthouse	44 14 57	66 23 38	10 29	4 36	20.8	15.4
	Annapolis Harbor: Prim Pt. light	44 41 34	65 47 20	10 49	4 41	27.5	20.4
	Haute Island: Lighthouse	45 14 55	65 00 45	11 07	5 27	33.0	24.4
	Cape Chignecto	45 19 00	64 57 00				
	Burntcoat Head: Lighthouse	45 18 40	63 48 30	0 27	7 27	50.5	37.4
New Brunswick.	Cape Enragé: Lighthouse	45 35 34	64 46 55				
	Cape Quaco: Lighthouse	45 19 30	65 32 00	11 21	5 56	30.0	22.2
	St. Johns: Partridge I. light	45 14 20	66 03 20	11 07	4 58	23.9	17.7
	Cape Lepreau: Lighthouse	45 03 40	66 27 40	11 04	5 26	24.5	18.2
	L'Etang Harbor: S. pt. tower	45 04 00	66 49 00	11 09	5 08	23.3	17.1
	St. Andrew: S. pt. light	45 04 06	67 02 52	11 00	5 00	24.9	18.2
	Campo Bello Island: Lighthouse, N. pt.	44 57 40	66 54 10				
	Grand Manan Island: Lighthouse, NE. pt.	44 45 52	66 44 00	11 02	5 21	22.5	16.7
	Gannet Rock: Lighthouse, NE. pt	44 30 38	66 47 00				
	Machias Island: Lighthouse	44 30 07	67 06 13	10 51	4 56	18.0	13.2
Maine.	Calais: Astronomical station	45 11 05	67 16 50	11 36	5 40	23.3	17.1
	Eastport: Cong. Church	44 54 15	66 59 14	11 09	5 05	20.9	15.2
	Quoddy Head: Lighthouse	44 48 55	66 57 04				
	Machias: Town Hall	44 43 01	67 27 22	11 02	4 59	15.5	11.3
	Petit Manan Island: Lighthouse	44 22 03	67 51 51				
	Bakers Island: Lighthouse	44 14 29	68 11 58				
	Mount Desert Rock: Lighthouse	43 58 08	68 07 44				
	Bangor: Thomas Hill	44 48 23	68 46 59	0 23	6 47	15.1	11.0
	Belfast: Methodist Church	44 25 29	69 00 19	11 35	5 22	11.7	8.6
	Rockland: Episcopal Church	44 06 06	69 06 52	11 09	4 55	11.0	8.1
	Matinicus Rock: Lighthouse	43 47 03	68 51 28	10 45	4 31	10.2	7.5
	Monhegan Island: Lighthouse	43 45 53	69 18 59				
	Seguin Island: Lighthouse	43 42 26	69 45 32				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Maine.	Bath: Winter St. Church	43 54 55	69 49 00	12 13	6 16	7.9	5.8
	Brunswick: College spire	43 54 29	69 57 44	......	......	....	....
	Augusta: Baptist Church	44 18 52	69 46 37	2 54	10 18	4.9	3.6
	Portland: Customhouse	43 39 28	70 15 18	11 06	4 51	10.1	7.3
	Portland Head lighthouse	43 37 23	70 12 30	......	......	....	....
	Cape Elizabeth: Lighthouse (west)	43 33 51	70 12 11	......	......	....	....
	Wood Island: Lighthouse	43 27 24	70 19 46	11 12	4 51	10.2	7.5
	Boon Island: Lighthouse	43 07 17	70 28 37	......	......	....	....
N. H.	Whale Back: Lighthouse	43 03 32	70 41 49	......	......	....	....
	Portsmouth: Navy-yard flagstaff	43 04 56	70 44 22	11 23	5 09	10.5	7.7
	Fort Constitution	43 04 16	70 42 34	......	......	....	....
	Hampton: Baptist Church	42 56 15	70 50 12	......	......	....	....
	Isles of Shoals: White I. lighthouse	42 58 02	70 37 25	11 19	4 58	10.0	7.3
Massachusetts.	Newburyport: Academy	42 48 30	70 52 28	11 23	5 10	9.1	6.6
	Plum I. lighthouse	42 48 55	70 49 10	......	......	....	....
	Ipswich: Lighthouse (rear)	42 41 07	70 46 00	11 17	5 04	10.1	7.4
	Annisquam Harbor: Lighthouse	42 39 43	70 40 55	11 13	5 00	10.1	7.4
	Cape Ann: Thatchers I. lighthouse (N.)	42 38 21	70 34 31	......	......	....	....
	Gloucester: Universalist Church	42 36 46	70 39 59	......	......	....	....
	Ten-pound I. lighthouse	42 36 07	70 39 58	11 02	4 49	10.2	7.5
	Beverly: Hospital Pt. lighthouse	42 32 48	70 51 23	......	......	....	....
	Salem: Derbys Wharf lighthouse	42 31 00	70 53 03	11 16	5 03	10.6	7.7
	Marblehead: Lighthouse	42 30 20	70 50 03	11 09	4 57	10.6	7.7
	Cambridge: Harvard Observatory	42 22 48	71 07 46	......	......	....	....
	Boston: Navy-yard flagstaff	42 22 22	71 03 05	11 27	5 17	11.0	8.1
	State House	42 21 28	71 03 50	......	......	....	....
	Little Brewster I. lighthouse	42 19 41	70 53 26	11 09	4 56	10.9	8.0
	Minots Ledge: Lighthouse	42 16 11	70 45 35	......	......	....	....
	Plymouth: Pierhead	41 58 44	70 39 12	......	......	....	....
	Gurnet lighthouse	42 00 12	70 36 04	11 23	5 11	10.8	7.9
	Barnstable: Lighthouse	41 43 20	70 16 52	11 36	5 25	11.6	8.5
	Cape Cod: Highlands lighthouse	42 02 23	70 03 40	......	......	....	....
	Chatham: Lighthouse (south)	41 40 17	69 57 01	12 11	5 57	4.6	3.4
	Monomoy Point: Lighthouse	41 33 34	69 59 39	12 00	5 48	4.3	3.1
	Nantucket: South Church	41 16 55	70 05 57	0 04	6 00	3.8	2.3
	Nantucket Shoals: Lightship	40 37 05	69 36 33	......	......	....	....
	Sankaty Head: Lighthouse	41 17 01	69 57 57	......	......	....	....
	Tarpaulin Cove: Lighthouse	41 28 08	70 45 29	7 51	1 51	2.8	1.7
	Vineyard Haven: W. Chop lighthouse	41 28 51	70 36 01	11 34	4 33	2.0	1.2
	Gay Head: Lighthouse	41 20 55	70 50 08	7 31	1 20	3.7	2.2
	Cuttyhunk: Lighthouse	41 24 52	70 57 01	7 36	0 59	4.3	2.6
	New Bedford: Baptist Church	41 38 10	70 55 36	7 57	1 18	5.2	3.1
Rhode Island.	Sakonnet Point: Lighthouse	41 26 30	71 13 30	7 40	1 05	4.5	2.6
	Beaver Tail: Lighthouse	41 26 58	71 24 00	7 40	1 09	4.7	2.8
	Newport: Flagstaff, torpedo station	41 29 07	71 19 40	7 48	1 00	4.4	2.6
	Bristol Ferry: Lighthouse	41 38 34	71 15 39	7 53	0 40	5.2	3.6
	Providence: Brown University Obsy	41 50 21	71 23 59	8 12	0 57	5.4	3.4
	Point Judith: Lighthouse	41 21 40	71 28 55	7 32	1 17	3.8	2.3
	Block Island: Lighthouse (SE.)	41 09 10	71 33 08	7 33	1 25	3.7	2.2
	Watch Hill Point: Lighthouse	41 18 14	71 51 32	8 49	2 38	3.2	2.1
Conn. and N. Y.	Montauk Point: Lighthouse	41 04 16	71 51 27	8 20	2 03	2.3	1.5
	Stonington: Lighthouse	41 19 31	71 54 49	9 09	3 03	3.2	2.1
	New London: Groton Monument	41 21 16	72 04 47	9 26	3 32	2.9	1.9
	Little Gull Island: Lighthouse	41 12 23	72 06 26	9 26	3 04	3.0	2.0
	Gardners Island: Lighthouse, N. pt	41 08 29	72 08 44	9 40	3 35	2.5	1.7
	Plum Island: Lighthouse, W. pt	41 10 25	72 12 43	......	......	....	....
	Saybrook: Lighthouse, Lynde Pt	41 16 17	72 20 37	10 29	4 11	4.3	2.8
	New Haven: Yale University Obsy	41 19 22	72 55 09	11 08	4 54	7.0	4.9

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Conn. and N. Y.	Bridgeport Harbor: Lighthouse	41 09 24	73 10 49	11 09	5 04	8.4	5.9
	Norwalk Island: Lighthouse	41 02 56	73 25 11	11 03	4 56	8.2	5.7
	Shinnecock Bay: Lighthouse	40 51 03	72 30 16	7 48	1 38	3.0	2.0
	Fire Island: Lighthouse	40 37 57	73 13 08	7 19	1 20	2.2	1.4
	Albany: New Dudley Observatory	42 39 13	73 46 42	5 13	0 46	2.8	1.8
	New York: Navy-yard flagstaff	40 42 02	73 58 51	8 44	2 49	5.3	3.4
	City Hall	40 42 44	74 00 24				
	Fort Wadsworth: Lighthouse	40 36 20	74 03 15	7 41	1 38	5.4	3.5
Pennsylvania, New Jersey, Delaware, Virginia, and Maryland.	Sandy Hook: Lighthouse (rear)	40 27 42	74 00 09	7 30	1 23	5.6	3.6
	Lightship	40 28 15	73 50 09				
	Navesink Highlands: N. lighthouse	40 23 48	73 59 10				
	Barnegat Inlet: Lighthouse	39 45 52	74 06 24	7 50	1 43	2.7	1.7
	Tuckers Beach: Lighthouse	39 30 22	74 17 08	7 48	1 42	4.2	2.7
	Absecon Inlet: Lighthouse	39 21 59	74 24 52	9 59	3 57	4.7	3.0
	Five Fathom Bank: Lightship	38 47 20	74 34 36				
	Cape May: Lighthouse	38 55 59	74 57 39	8 16	1 47	5.6	3.6
	Philadelphia, Pa.: University Obsy	39 58 02	75 16 39	1 28	8 58	6.2	4.4
	Navy-yard flagstaff, League I	39 53 14	75 10 32	0 53	8 02	7.0	5.2
	Wilmington, Del.: Town Hall	39 44 27	75 33 03	12 00	6 40	6.7	4.9
	Cape Henlopen: Lighthouse	38 46 42	75 05 03	8 17	1 50	5.4	3.5
	Assateague Island: Lighthouse	37 54 40	75 21 23				
	Hog Island: Lighthouse	37 23 46	75 41 59				
	Cape Charles: Lighthouse	37 07 22	75 54 24	8 03	2 19	3.0	2.0
	Baltimore: Johns Hopkins Obsy	39 17 48	76 36 30	6 34	0 44	1.4	1.0
	Annapolis: Naval Academy Observatory	38 58 53	76 29 08	4 39	10 53	1.0	0.8
	Point Lookout: Lighthouse	38 02 19	76 19 20	0 31	6 52	1.7	1.1
	Washington, D. C.: Navy-yard flagstaff	38 52 30	76 59 45	7 42	1 56	3.5	2.5
	Naval Observatory	38 55 14	77 03 57				
	Capitol dome	38 53 20	77 00 36				
	Old Point Comfort: Lighthouse	37 00 06	76 18 24	8 44	2 17	3.0	2.0
	Norfolk: Navy-yard flagstaff	36 49 33	76 17 46	9 05	2 47	3.2	2.1
	Richmond, Va.: Capitol	37 32 16	77 26 04	4 30	11 55	4.3	2.9
	Cape Henry: Lighthouse	36 55 35	76 00 27	7 53	1 43	3.2	2.1
North Carolina.	Elizabeth City: Courthouse	36 17 58	76 13 23				
	Edenton: Courthouse	36 03 24	76 36 31				
	Currituck Beach: Lighthouse	36 22 36	75 49 51	7 37	1 26	3.4	2.2
	Bodie Island: Lighthouse	35 49 07	75 33 49				
	Cape Hatteras: Lighthouse	35 15 17	75 31 16				
	Ocracoke: Lighthouse	35 06 32	75 59 11	7 00	0 45	2.2	1.5
	Newbern: Episcopal spire	35 06 21	77 02 24				
	Cape Lookout: Lighthouse	34 37 22	76 31 29	6 29	0 20	4.4	3.0
	Beaufort, N. C.: Courthouse	34 43 05	76 39 48	7 21	1 08	3.3	2.3
	Frying-Pan Shoals: Lightship	33 34 26	77 49 12				
S. Carolina.	Georgetown: Episcopal Church	33 22 08	79 16 49	8 39	3 38	4.3	2.9
	Lighthouse, North I	33 13 21	79 10 55				
	Cape Romain: Lighthouse	33 01 06	79 22 19	6 59	0 50	5.9	4.1
	Charleston: Lighthouse, Morris I	32 41 43	79 52 54				
	St. Michael's Church	32 46 34	79 55 49	7 20	1 10	6.0	4.2
	Beaufort, S. C.: Episcopal Church	32 26 02	80 40 27	8 10	2 06	8.5	5.9
	Port Royal: Martins Industry lightship	32 05 33	80 33 15				
Georgia.	Tybee Island: Lighthouse	32 01 20	80 50 37	7 10	1 04	7.9	5.5
	Savannah: Exchange spire	32 04 52	81 05 26	8 13	3 07	7.6	5.3
	Sapelo Island: Lighthouse	31 23 28	81 17 01	7 30	1 24	8.4	5.8
	Darien: Winnowing House	31 21 54	81 25 39	7 40	1 44	7.5	5.2
	St. Simon: Lighthouse	31 08 02	81 23 30	7 30	1 27	7.5	5.3
	Brunswick: Academy	31 08 51	81 29 26	8 00	1 57	7.8	5.4

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range Spg.	Range Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Florida.	Amelia Island: Lighthouse	30 40 23	81 26 26				
	Fernandina: Astronomical station	30 40 18	81 27 47	7 39	1 31	6.9	4.8
	St. Johns River: Lighthouse	30 23 36	81 25 27	7 36	1 33	5.4	3.7
	Jacksonville: Methodist Church	30 19 43	81 39 14				
	St. Augustine: Presbyterian Church	29 53 20	81 18 41				
	Lighthouse	29 53 07	81 17 12	8 12	2 00	5.3	3.6
	Cape Canaveral: Lighthouse	28 27 37	80 32 30	8 00	1 52	5.9	4.0
	Jupiter Inlet: Lighthouse	26 56 54	80 04 48	8 00	2 00	1.8	1.2
	Fowey Rocks: Lighthouse	25 35 25	80 05 41	8 20	2 16	2.6	1.3
	Carysfort Reef: Lighthouse	25 13 17	80 12 40	8 21	2 08	2.7	1.4
	Alligator Reef: Lighthouse	24 51 02	80 37 08	8 22	2 00	2.6	1.3
	Sombrero Key: Lighthouse	24 37 36	81 06 40	8 24	2 05	1.9	1.0
	Sand Key: Lighthouse	24 27 10	81 52 40	8 40	2 20	1.5	0.8
	Key West: Lighthouse	24 32 58	81 48 04	9 20	2 36	1.6	0.9
	Loggerhead Key: Lighthouse	24 38 04	82 55 42	9 44	3 21	1.4	0.8
	Sanibel Island: Lighthouse	26 27 11	82 00 43	12 17	6 10	2.3	1.2
	Gasparilla Island: Lighthouse	26 43 06	82 15 34	0 42	6 19	1.4	0.7
	Tampa Bay: Egmont Key light	27 36 04	82 45 40	11 32	5 07	1.8	0.9
	Cedar Keys: Ast. station, Depot Key	29 07 29	83 01 57	0 42	7 13	3.1	1.5
	Seahorse Key light	29 05 49	83 03 58				
	St. Marks: Fort St. Marks	30 09 03	84 12 42	2 00	8 30	2.6	1.2
	Apalachicola: Flagstaff	29 43 32	84 59 12	[12 10]	[5 35]	[2.5]	
	Cape St. George: Lighthouse	29 35 18	85 02 54				
	Cape San Blas: Lighthouse	29 40 00	85 21 30	[11 10]	[4 55]	[2.1]	
	Pensacola: Lighthouse	30 20 47	87 18 32				
	Navy-yard chimney	30 20 49	87 16 06	[11 28]	[4 20]	[1.7]	
Alabama, Mississippi, and Louisiana.	Sand Island: Lighthouse (front)	30 11 19	88 03 02				
	Mobile Point: Lighthouse	30 13 44	88 01 26	[11 25]	[3 09]	[1.5]	
	Mobile: Episcopal Church	30 41 26	88 02 28	[1 35]	[6 50]	[2.1]	
	Horn Island: Lighthouse	30 13 23	88 31 39	[12 00]	[5 40]	[2.0]	
	East Pascagoula: Coast Survey station	30 20 42	88 32 45	[0 20]	[5 45]	[2.3]	
	Mississippi City: Coast Survey station	30 22 54	89 01 57				
	Ship Island: Lighthouse	30 12 53	88 57 56				
	Cat Island: Lighthouse	30 13 57	89 09 41	[0 23]	[6 35]	[2.1]	
	Chandeleur: Lighthouse	30 02 58	88 52 19	[11 53]	[5 33]	[1.8]	
	Mouth Mississippi River: Pass a l'Outre light	29 11 30	89 02 28	[11 15]	[5 00]	[1.6]	
	S. Pass light (East Jetty)	28 59 28	89 08 08	[10 55]	[4 42]	[1.7]	
	SW. Pass light	28 58 22	89 23 30	[10 54]	[4 41]	[1.9]	
	New Orleans: United States Mint	29 57 46	90 03 28				
	Barataria Bay: Lighthouse	29 16 30	89 56 43	[11 00]	[4 47]	[2.1]	
	Timbalier Island: Lighthouse	29 02 49	90 21 25	[11 50]	[5 38]	[2.0]	
	Ship Shoal: Lighthouse	28 54 56	91 04 15	[0 18]	[6 33]	[2.2]	
	Southwest Reef: Lighthouse	29 23 36	91 30 14	[0 40]	[6 56]	[2.0]	
	Calcasieu Pass: Lighthouse	29 46 55	93 20 43	2 17	8 41	1.7	1.3
	Sabine Pass: Lighthouse	29 43 04	93 51 00	3 17	9 36	0.9	0.6
Texas.	Galveston: Cathedral, N. spire	29 18 17	94 47 26	[4 18]	[10 33]	[1.4]	
	Lighthouse, Bolivar Pt.	29 22 05	94 46 00	[4 07]	[10 23]	[1.6]	
	Matagorda: Coast Survey station	28 41 29	95 57 26				
	Lighthouse	28 20 18	96 25 28	[4 35]	[10 47]	[1.6]	
	Indianola: Coast Survey station	28 32 28	96 31 01				
	Lavaca: Coast Survey station	28 37 36	96 37 21				
	Aransas Pass: Lighthouse	27 51 53	97 03 23	[4 25]	[10 35]	[1.6]	
	Brazos Santiago: Light, S. end Padre I.	26 04 16	97 10 00				
	Point Isabel: Lighthouse	26 04 36	97 12 28				
	Rio Grande del Norte: Obsy. N. side of entrance	25 57 22	97 08 57	[1 55]	[8 03]	[1.4]	

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Mexico.	San Fernando River: Entrance	25 23 40	97 21 25	.....	.....	.....	.....
	Santander River: Entrance	23 46 20	97 46 55	.....	.....	.....	.....
	Mount Mecate: Summit	22 38 40	98 04 55	.....	.....	.....	.....
	Tampico: Lighthouse	22 15 50	97 49 55	[1 06]	[7 19]	[1.3]	.....
	Cape Roxo	21 35 00	97 22 00	.....	.....	.....	.....
	Lobos Cay: Lighthouse	21 28 12	97 13 00	.....	.....	.....	.....
	Tuxpam Reefs: Middle islet	21 03 00	97 13 35	.....	.....	.....	.....
	Mexico: Tacubaya National Obsy	19 24 18	99 11 38	.....	.....	.....	.....
	Bernal Chico: Middle of islet	19 39 50	96 24 39	.....	.....	.....	.....
	Zempoala Point: Extreme	19 27 26	96 20 22	.....	.....	.....	.....
	Vera Cruz: San Juan d'Ulloa light	19 12 30	96 07 57	[2 49]	[8 38]	[2.4]	.....
	Sacrificios Island	19 10 10	96 05 30	.....	.....	.....	.....
	Orizaba Mountain: 17,400 feet	19 04 00	97 15 55	.....	.....	.....	.....
	Cofre de Perote Mount: 14,000 feet	19 29 30	97 07 30	.....	.....	.....	.....
	Alvarado: E. side of entrance	18 49 00	95 44 48	.....	.....	.....	.....
	Roca Partida: Summit	18 44 00	95 11 14	.....	.....	.....	.....
	Tuxtla, volcano: Summit	18 29 00	95 08 00	.....	.....	.....	.....
	Montepio: Landing place	18 40 00	95 05 12	.....	.....	.....	.....
	Zapotitlan Point: Lighthouse	18 34 00	94 50 00	.....	.....	.....	.....
	San Juan Point: Lighthouse	18 19 45	94 38 57	.....	.....	.....	.....
	Puerto Mexico: Lighthouse	18 08 56	94 24 47	.....	.....	.....	.....
	Santa Ana Lagoon: Entrance	18 18 49	93 51 53	.....	.....	.....	.....
	Tupilco River: Entrance	18 26 44	93 25 25	.....	.....	.....	.....
	Tabasco River: Lighthouse	18 39 30	92 42 00	.....	.....	.....	.....
	Carmen Island: NE. pt	18 47 08	91 30 50	.....	.....	.....	.....
	Laguna de Terminos: Vigia tower, W. end Carmen I	18 38 44	91 50 17	[12 16]	[6 00]	[1.6]	.....
Yucatan.	Paypoton Mount: Summit	19 38 00	90 43 27	.....	.....	.....	.....
	Lerma: Church	19 48 24	90 36 11	.....	.....	.....	.....
	Campeche: Lighthouse	19 50 20	90 32 20	2 59	9 28	2.1	1.3
	Fort San José	19 51 36	90 30 51	.....	.....	.....	.....
	Point Palmas	21 02 00	90 22 00	.....	.....	.....	.....
	Sisal: Fort light	21 10 06	90 02 37	10 20	4 10	1.8	0.9
	Madagascar Reef: Center	21 26 30	90 18 27	.....	.....	.....	.....
	Progreso: Lighthouse	21 17 00	89 39 30	.....	.....	.....	.....
	Silan: Village	21 23 00	88 54 27	.....	.....	.....	.....
	Lagartos: Village	21 36 30	88 10 27	.....	.....	.....	.....
	Cape Catoche: Lighthouse	21 35 50	87 04 10	9 30	3 19	1.5	0.8
	Arcas Cays: Lighthouse	20 12 45	91 57 45	[12 06]	[5 50]	[1.6]	.....
	Obispo Shoal: 16-foot spot	20 29 00	92 13 27	.....	.....	.....	.....
	New Bank: Center	20 32 00	91 52 27	.....	.....	.....	.....
	Triangles, E. reef: Beacon	20 54 54	92 12 47	[12 00]	[5 45]	[1.6]	.....
	Triangles, W. reef: Cay at SW. end	20 58 00	92 18 57	.....	.....	.....	.....
	Bajo Nuevo Reef: Center	21 50 00	92 04 26	.....	.....	.....	.....
	Arenas Cays: NW. Cay	22 07 10	91 24 21	.....	.....	.....	.....
	Alacran Reef: Perez Cay	22 23 36	89 41 45	.....	.....	.....	.....
	Contoy Island: Lighthouse	21 33 00	86 48 00	.....	.....	.....	.....
	Mugeres Island: Lighthouse	21 12 00	86 43 39	9 20	3 08	1.6	0.9
	Cancun Island: Nisuc Pt	21 03 00	86 46 45	.....	.....	.....	.....
	Cozumel Island: N. pt. lighthouse	20 35 50	86 43 55	8 20	2 08	1.5	0.8
	S. pt. lighthouse	20 16 20	86 59 04	.....	.....	.....	.....
	Ascension Bay: Allen Pt	19 46 55	87 28 27	.....	.....	.....	.....
	Chinchorro Bank: Cayo Lobos light	18 23 20	87 23 40	.....	.....	.....	.....
Belize.	Halfmoon Cay: Lighthouse	17 12 15	87 32 30	.....	.....	.....	.....
	Mauger Cay, NW. end: Lighthouse	17 36 15	87 46 30	.....	.....	.....	.....
	Glover Reef: SW. Cay	16 42 20	87 50 50	.....	.....	.....	.....
	English Cay: Lighthouse	17 19 30	88 03 20	.....	.....	.....	.....
	St. Georges Cay: Center	17 33 15	88 04 45	.....	.....	.....	.....

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Belize.	Sand-Fly Cays: Hut, S. end	16 57 50	88 06 05				
	South Water Cay: Center	16 48 50	88 05 36				
	Belize: Fort George light	17 29 20	88 11 20	8 00	1 50	1.5	0.8
	North Standing Creek: Entrance	16 57 40	88 13 48				
	Sittee Point: Cay	16 47 45	88 15 15				
	Cockscomb Mount: Summit, 4,000 feet	16 48 10	88 37 40				
	Placentia Point: Huts on point	16 30 54	88 22 13				
	Icacos Point: S. extreme	16 14 15	88 35 51				
	Sarstoon River: Entrance	15 54 00	88 56 20				
Guat.	Dulce River: Entrance, W. side	15 49 45	88 46 22	9 00	2 50	2.0	1.1
	Dulce Gulf: Fort St. Philip	15 38 00	89 01 36				
	Izabal	15 24 20	89 09 15				
Honduras.	Hospital Bight: Hut, N. pt. of entrance	15 52 20	88 33 22				
	Cape Three Points: NW. extreme	15 57 45	88 38 50				
	Seal Cays: S. Cay	16 08 00	88 20 15				
	Omoa: Entrance	15 47 11	88 04 31				
	Cape Triunfo: Bluff pt	15 48 45	87 27 46				
	Congrehoy Peak: Summit, 8,040 feet	15 38 00	86 55 00				
	Truxillo: Fort	15 55 45	85 59 18				
	Utilla Island: S. Cay	16 03 40	86 59 15				
	Hog Islands: Highest hill on W. islet	15 58 00	86 32 09				
	Roatan: Center of Coxen Cay	16 18 00	86 34 27	7 35	1 23	3.5	1.8
	Port Royal, NW. pt. of George Cay	16 24 20	86 18 41				
	Bonacca Island: Summit, 1,200 feet	16 28 00	85 55 00	8 50	2 38	1.5	0.8
	Misteriosa Bank: S. Point	18 44 00	84 02 00				
	Swan Islands: Light on W. pt. of west island	17 24 21	83 56 25				
	Great Rock Head: Bluff extreme	15 53 00	85 27 10				
	Cape Camaron	16 00 00	85 03 00				
	Brewers Lagoon: E. side of entrance	15 51 50	84 38 33				
	Patuca River: E. side of entrance	15 48 50	84 17 10				
	Carataska Lagoon: E. side of entrance	15 23 40	83 42 36				
Nicaragua.	Cape Gracias-á-Dios: Lighthouse	15 00 04	83 09 22	10 20	4 07	2.0	1.1
	Caxones Reef: Great Hobby Islet	16 03 30	83 08 20				
	Gorda Bank: Gorda Cay	15 52 00	82 23 27				
	Farrall Rock: Center	15 51 00	82 18 07				
	Halfmoon Cay: Center	15 08 50	82 42 08				
	Alargate Reef: E. pt	15 07 00	82 20 00				
Miskito Shore.	Miskito Cays: S. end	14 21 12	82 45 57				
	Rosalind Bank: NW. extreme	16 54 00	80 51 27				
	Serranilla Bank: Beacon Cay	15 47 45	79 50 53	4 00	10 13	2.0	1.1
	Serrana Bank: Little Cay	14 21 33	80 15 20	4 00	10 13	2.0	1.1
	Quita Sueño Bank: S. extreme of reef	14 08 00	81 08 21				
	Spit at NW. end	14 30 00	81 07 21				
	Roncador Cay: S. pt	13 34 30	80 05 05				
	Old Providence: Isabel House	13 22 54	81 21 26	4 00	10 13	1.0	0.5
	St. Andrews Island: SW. cove, Entrance I.	12 31 40	81 43 06				
	Courtown Cays: Middle Cay	12 24 00	81 27 53				
	Albuquerque Bank: Smith Cay	12 10 00	81 49 54				
	Pearl Cays: Colombilla Cay	12 22 35	83 23 10	1 50	8 03	2.0	1.1
	Pearl Cays Lagoon: Mosquito Pt	12 20 39	83 37 12				
	Bluefields: Schooner Pt	11 59 00	83 41 57	1 40	7 52	2.0	1.1
	Little Corn Island: Gun Pt	12 17 30	82 58 35				
	Great Corn Island: Wells N. of Quin Bluff.	12 09 17	83 03 35	1 35	7 47	2.0	1.1
	Greytown: Lighthouse	10 56 15	83 42 15	1 00	7 13	1.5	0.8
C.R.	Mount Cartago: Peak, 11,100 feet	10 02 00	83 48 30				
	Port Limon: Monument, Park, opp. P. O.	10 00 16	83 00 57	1 00	7 13	1.6	0.9

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Panama.	Carreta Point: Extreme	9 38 30	82 39 06				
	Almirante Bay: Tirbi Pt., Extreme	9 26 16	82 20 40				
	Columbus I., Lime Pt.	9 25 00	82 19 28				
	Shepherd I., Summit	9 14 24	82 19 36				
	Bocas del Toro, Radio Tel. Sta.	9 20 17	82 14 29	0 42			
	Crawl Cay Channel: Crawl Cay	9 14 53	82 07 48				
	Blanco Peak: Summit, 11,740 feet	9 17 00	83 03 00				
	Chiriqui Lagoon: Valiente Peak, Summit	9 10 30	81 54 06				
	Escudo de Veragua: NW. Pt. of Island	9 06 00	81 33 57				
	Chagres: San Lorenzo Castle	9 19 27	80 00 22				
	Toro Point: Lighthouse	9 22 39	79 57 13				
	Colon: Lighthouse	9 22 09	79 54 42	0 06	6 18	1.1	0.6
	Porto Bello: Ft. St. Geronimo	9 33 20	79 39 13				
	Gulf of San Blas: Cape San Blas	9 34 00	78 57 00				
	Caledonia Harbor: Dobbin Cay	8 53 52	77 40 53	11 30	5 17	1.5	0.8
	Port Carreto: Peak	8 46 30	77 32 15				

WEST COAST OF NORTH AMERICA.

Coast.	Place.	Lat. N.	Long. W.	H. W.	L. W.	Spg.	Neap.
Alaska.	Point Barrow: Highest lat. of Alaska	71 23 30	156 27 00	11 41	5 33	0.6	0.2
	Icy Cape: Extreme	70 16 00	161 47 30				
	Cape Lisburne: 849 feet	68 52 00	166 06 00				
	Cape Krusenstern: Extreme	67 09 00	163 34 00				
	Chamisso Island: Summit	66 14 30	161 45 00	7 45	1 50	2.0	0.6
	Cape Espenberg: Extreme	66 32 00	163 36 00				
	Diomede Island: Fairway Rock	65 35 30	168 40 00				
	Cape Prince of Wales: W. pt.	65 33 30	168 00 00				
	Port Clarence: Point Spencer	65 16 40	166 46 30	6 10	1 10	1.1	0.9
	Cape Nome: Extreme	64 26 00	165 05 00	[2 05]	[8 25]	[2.1]	
	St. Michael: Fort	63 26 00	162 02 30	[8 05]	[1 20]	[4.5]	
	Stuart Island: W. pt.	63 34 30	162 42 30				
	Cape Romanzof: Extreme	61 40 00	166 15 00				
	St. Lawrence Island: E. pt.	63 16 00	168 41 00				
	St. Matthew Island: SE. pt.	60 18 00	172 02 00	4 40	11 00	3.1	1.6
	Pinnacle Islet: Summit, 930 feet	60 13 00	172 36 00				
	Nunivak Island: Cape Etolin	60 25 22	166 08 30				
	Hagenmeister Island	58 48 31	160 50 00				
	Cape Menchikof: Extreme	57 30 24	157 58 30				
	Port Moller	55 54 59	160 34 54				
	St. George Island: S. side	56 34 23	169 39 50				
Aleutian Islands.			Long E.				
	Attu Island: Chichagof Harbor	52 56 01	173 12 24	3 35	9 48	5.7	2.9
	Kiska Island: Kiska Harbor, Ast. sta.	51 59 04	177 30 00	3 30	9 43	5.2	2.7
	Amchitka Island: Constantine Harbor	51 23 39	179 12 06				
			Long W.				
	Adakh Island: Bay of Islands	51 49 18	176 52 00	3 25	9 38	5.0	2.6
	Atka Island: Nazan Bay (church)	52 10 36	174 15 18				
	Pribilof Island: St. Paul I., village	57 07 19	170 17 52	4 17	10 29	2.7	1.4
	Unalaska Island: C. S. station, Iliuliuk	53 52 54	166 31 44	3 50	9 58	2.9	1.5
	Sannakh Reefs: S. edge	54 13 30	162 38 00	12 13	6 10	5.7	2.8
	Sannakh Island: NE. end	54 26 12	162 18 00				
	Unga Island	55 20 45	160 38 39	2 40	8 55	8.2	4.1
	Popof Island: Humboldt I.	55 19 17	160 31 14				
	Nagai Island: Sanborn Harbor	55 07 36	159 56 06				
	Koniushi Island: NW. harbor	55 03 17	159 23 05				
	NE. harbor	54 58 25	159 22 18				
	Simeonof Island: Simeonof Harbor	54 55 30	159 15 03	2 20	8 33	7.5	3.8

44325°—18——19

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Alaska.	Cape Strogonof: Extreme	56 48 00	158 46 00	......	......	......	....
	Chignik Bay: Anchorage	56 19 20	158 24 24	......	......	......	....
	Anowik Island: S. end	56 05 13	156 39 19	1 45	7 58	8. 1	4. 0
	Lighthouse Rocks	55 45 24	157 27 04	......	......	......	....
	Chirikof Island	55 48 22	155 42 51	......	......	......	....
	Kodiak Island, St. Paul Harbor: Cove NW. of village	57 47 57	152 21 21	0 16	6 24	9. 0	4. 5
	Port Etches	60 20 43	146 37 38	0 50	7 05	10. 1	5. 1
	Middleton Island	59 27 22	146 18 45	......	......	......	....
	Mount St. Elias: Summit	60 20 45	141 00 12	......	......	......	....
	Yakutat Bay: Port Mulgrave	59 33 42	139 46 16	0 34	6 41	9. 5	5. 0
	Lituya Bay	58 36 57	137 40 06	......	......	......	....
	Sitka: Middle of parade ground	57 02 52	135 19 31	0 06	6 17	9. 9	5. 2
	Juneau	58 18 00	134 24 00	0 45	6 56	18. 6	9. 7
	Wrangell: Ast. station	56 27 00	132 23 00	0 30	6 39	17. 7	9. 2
Queen Charlotte Is.	North Island: N. pt	54 15 25	133 02 00	......	......	......	....
	Cape Knox: Extreme	54 10 30	133 05 10	......	......	......	....
	Port Kuper: Sansum I	52 56 31	132 09 06	0 00	6 12	11. 5	6. 1
	Forsyth Point: Extreme	52 09 07	131 03 20	......	......	......	....
	St. James Cape: S. extreme	51 54 00	131 01 26	......	......	......	....
	Cumshewa Harbor: N. side of entrance	53 02 00	131 31 00	......	......	......	....
	Skidegate Bay: Rock on bar	53 22 20	131 51 00	0 07	6 19	12. 8	6. 7
	Rose Spit Point: Extreme	54 13 00	131 37 00	......	......	......	....
	Masset Harbor: Masset village	54 02 14	132 11 16	......	......	......	....
	Cape Edenshaw: Extreme	54 05 50	132 26 10	......	......	......	....
Vancouver Island.	Hecate Bay: Observatory Islet	49 15 22	125 55 43	12 15	6 08	10. 0	5. 8
	Stamp Harbor: Observatory Islet	49 13 46	124 50 07	0 45	7 20	12. 4	7. 1
	Island Harbor: Observatory Islet	48 54 41	125 16 54	......	......	......	....
	Cape Beale: Lighthouse	48 47 23	125 13 14	12 20	6 15	9. 9	5. 7
	Hesquiat Harbor: Boat Cove	49 27 31	126 24 53	12 05	5 56	10. 3	5. 9
	Estevan Point: S. extreme	49 22 07	126 31 58	......	......	......	....
	Nootka Sound: Friendly Cove	49 35 31	126 36 58	12 05	5 55	9. 8	5. 6
	Port Langford: Colwood Islet	49 47 20	126 56 31	......	......	......	....
	Esperanza Inlet: Observatory Rock	49 52 45	126 59 21	11 55	5 45	9. 7	5. 5
	Kyuquot Sound: Shingle Point	49 59 55	127 08 56	11 50	5 38	9. 3	5. 3
	Nasparti Inlet: Head Beach	50 11 21	127 37 24	11 47	5 34	9. 3	5. 3
	Cook Cape: Solander I	50 06 31	127 56 46	......	......	......	....
	North Harbor: Observatory Rock	50 29 25	128 03 05	......	......	......	....
	Hecate Cove: Kitten Islet	50 32 26	127 35 44	......	......	......	....
	Cape Scott: Summit	50 46 41	128 26 11	......	......	......	....
	Bull Harbor, Hope Island: N. pt. Indian I.	50 54 47	127 55 29	0 10	6 22	10. 7	5. 6
	Port Alexander: Islet in center	50 50 49	127 39 23	0 32	6 44	11. 6	6. 1
	Beaver Harbor: Shell Islet	50 42 36	127 24 33	0 30	6 42	11. 5	6. 0
	Cormorant I.: Yellow Bluff in Alert Bay.	50 35 02	126 56 56	0 55	7 08	12. 8	6. 7
	Baynes Sound: Beak Pt	49 36 29	124 50 44	4 45	11 00	10. 6	6. 6
	Nanoose Harbor: Entrance Rock	49 15 43	124 07 32	4 52	11 18	10. 2	6. 4
	Nanaimo: Lighthouse	49 12 50	123 48 11	......	......	......	....
	Benson's House	49 10 15	123 56 02	4 40	11 05	9. 8	6. 1
	Victoria: Lighthouse	48 25 26	123 23 31	[2 17]	[8 31]	[5. 7]	....
	Esquimalt: Fisgard I. light	48 25 50	123 26 48	[2 00]	[8 14]	[5. 8]	....
	Race Island: Lighthouse	48 17 53	123 31 47	......	......	......	....
	Port San Juan: Pinnacle Rock	48 33 30	124 27 37	......	......	......	....
British Col.	Port Simpson: Methodist Church Spire	54 33 20	130 26 09	0 15	......	20	6. 5
	Prince Rupert Hbr.: Fairview Obs. Spot	54 17 17	130 21 33	0 50	......	24, 17	16
	Port Harvey: Tide Pole Islet	50 33 58	126 16 06	1 55	8 10	14. 1	7. 4
	Port Neville: Robber's Nob	50 31 09	126 03 47	2 30	8 47	16. 0	8. 3
	Knox Bay, Thurlow Island: Stream at head of bay	50 24 15	125 38 26	3 40	10 00	15. 7	7. 7
	Valdes Island: S. pt	50 02 42	125 14 34	4 45	10 15	7. 2	4. 8
	Howe Sound: Plumper Cove	49 24 39	123 28 46	5 38	11 58	9. 0	5. 6

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
British Col.	Atkinson Point: Lighthouse	49 19 42	123 15 54	5 20	11 35	7.8	4.9
	Vancouver, Burrard Inlet: Govt. Reserve, English Bay	49 16 18	123 11 26	5 28	12 01	8.2	5.0
	Fraser River: Garry Pt	49 07 04	123 11 27	5 11	11 23	7.0	4.4
	New Westminster: Military barracks	49 13 01	123 53 52				
	Point Roberts: Parallel station	49 00 00	123 04 52				
	Semiamoo Bay: Parallel station	49 00 00	122 44 56	4 59	11 10	7.1	4.6
Washington.	Admiralty Head: Lighthouse	48 09 19	122 40 34				
	Steilacoom: Methodist Church	47 10 20	122 35 51	4 46	11 04	11.0	7.2
	Seattle: C. S. ast. station	47 35 54	122 19 59	4 22	10 33	9.2	6.0
	Port Townsend: C. S. ast. station	48 06 56	122 44 58	3 47	9 32	6.2	4.0
	Smith Island: Lighthouse	48 19 07	122 50 36	3 40	9 28	5.6	3.7
	New Dungeness: Lighthouse	48 10 52	123 06 31	2 42	8 34	5.0	3.3
	Port Angeles: Ediz Hook lighthouse	48 08 24	123 24 07	2 10	8 23	5.3	3.4
	Cape Flattery: Lighthouse	48 23 30	124 44 06	0 08	6 16	7.1	4.1
	Cape Shoalwater: Lighthouse	46 43 00	124 04 25				
	Cape Disappointment: Lighthouse	46 16 29	124 03 11	12 22	6 19	7.7	4.5
	Bremerton: Navy-yard flagstaff	47 33 43	122 37 59	4 27	10 35	9.4	6.1
	Tacoma: St. Luke's Church	47 15 32	122 26 26	4 32	10 45	9.8	6.4
Oregon.	Astoria: Flagstaff	46 11 19	123 49 42	0 15	6 42	7.8	4.7
	Yaquina Head: Lighthouse	44 40 35	124 04 40	11 50	5 37	7.3	4.3
	Cape Arago, or Gregory: Lighthouse	43 20 36	124 22 31	11 55	5 49	6.0	3.5
	Cape Blanco: Lighthouse	42 50 22	124 33 30				
California.	Crescent City: Lighthouse	41 44 36	124 12 10	11 33	5 15	5.8	3.4
	Trinidad Head: Lighthouse	41 03 01	124 09 03	11 27	5 11	5.7	3.3
	Eureka: Methodist Church	40 48 11	124 09 41	11 57	5 45	5.7	3.3
	Humboldt: Lighthouse	40 41 37	124 16 26	11 33	5 19	5.3	3.1
	Cape Mendocino: Lighthouse	40 26 18	124 24 25	11 00	4 50	4.7	3.0
	Point Arena: Lighthouse	38 57 12	123 44 27	10 36	4 21	4.1	2.6
	Point Reyes: Lighthouse	37 59 39	123 01 24	11 23	5 08	5.1	3.2
	San Francisco: Davidson Observatory	37 47 28	122 25 43	12 07	5 34	5.1	3.2
	Presidio	37 47 30	122 27 49	11 43	5 07	4.9	3.1
	Berkeley Univ. Obsy	37 52 24	122 51 41				
	Mare Island: Chronom. and Time Sta., Navy-yard	38 05 56	122 16 24	1 05	7 15	5.6	3.7
	Benicia: Church	38 03 05	122 09 23	1 35	7 48	5.6	3.7
	Farallon Islet: Lighthouse	37 41 51	123 00 07	10 40	4 25	4.5	2.9
	Santa Clara: Catholic Church	37 20 49	121 56 26				
	Mount Hamilton: Obs. peak	37 21 03	121 36 40				
	San Jose: Spire	37 19 58	121 53 39				
	Pigeon Point: Lighthouse	37 10 49	122 23 39				
	Santa Cruz: Warehouse flagstaff	36 57 31	122 01 29	10 54	4 27	5.2	3.3
	Monterey: C. S. azimuth station	36 35 21	121 52 59	10 43	4 24	4.8	3.1
	Point Pinos: Lighthouse	36 37 55	121 56 02				
	Piedras Blancas: Lighthouse	35 39 50	121 17 06				
	Point Conception: Lighthouse	34 26 49	120 28 18				
	Santa Barbara: N. tower, Mission Church	34 26 10	119 42 42	9 37	3 15	4.8	2.2
	San Buenaventura: C. S. ast. station	34 15 46	119 15 56	9 53	3 21	4.9	2.2
	Pt. Fermin, San Pedro Bay: Lighthouse	33 42 14	118 17 41	9 36	3 13	5.5	2.5
	Los Angeles: Courthouse	34 03 05	118 14 32				
	Point Loma: Lighthouse	32 39 48	117 14 37	9 29	3 07	5.2	2.3
	San Diego: C. S. ast. station	32 43 06	117 09 41	9 32	3 20	5.1	2.3
	Mexican Boundary: Obelisk	32 31 58	117 07 32				
	San Miguel Island: Seal Pt	34 04 19	120 21 55	9 23	3 02	4.9	2.2
	Santa Rosa Island: E. pt	33 56 30	119 58 29				
	Santa Cruz Island: NE. pt	34 03 12	119 33 51	9 29	3 06	4.9	2.2
	Anacapa Island: E. pt	34 00 25	119 23 04				
	Santa Barbara Island: Summit	33 28 16	119 02 29				
	San Nicolas Island: Summit	33 14 55	119 31 19	9 20	3 04	4.9	2.2
	Santa Catalina Island: Catalina Peak	33 23 09	118 24 05	9 28	3 08	5.1	2.3

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Lower California.	Ensenada Harbor: Head of bay, close to beach	31 51 10	116 38 05	9 28	3 06	5.0	2.2
	San Tomas: NW. shore of cove	31 33 04	116 40 51				
	Colnett Bay: Head of bay	30 57 39	116 17 28	9 27	3 05	5.8	2.6
	San Martin Island: Hassler Cove	30 28 58	116 06 46				
	Port San Quentin: Sextant Pt	30 22 16	115 59 07	9 23	3 00	4.9	2.2
	San Geronimo Island: Bight at E. end	29 47 20	115 48 12				
	Canoas Point: High bluff	29 25 29	115 12 14				
	Guadeloupe: North pt	29 10 50	118 18 30				
	La Playa Maria: Mound on W. side	28 56 06	114 31 06	9 15	2 53	7.6	3.4
	Santa Rosalia Bay: Obs. spot, Cairn	28 40 16	114 14 15				
	Lagoon Head: Highest pt. of crater	28 14 26	114 06 21				
	Cerros Island: SE. extremity	28 03 52	115 11 32	9 05	2 42	7.8	3.5
	San Benito Island: Summit of W. island	28 18 08	115 36 10				
	San Bartolomé: N. side of entrance	27 39 35	114 54 27	9 00	2 37	8.2	2.8
	Asuncion Island: Summit of island	27 06 10	114 17 25				
	San Ignacio Point: Extreme	26 45 45	113 16 25				
	Abreojos Point: Extreme of rocky ledge	26 42 49	113 35 04	9 00	2 48	6.7	2.3
	San Domingo Point: Edge of cliff	26 18 56	112 41 44				
	San Juanico Point: Knoll	26 03 18	112 17 52	8 29	2 17	5.7	1.6
	Alijos Rocks: South Rock	24 58 00	115 51 54				
	Cape San Lazaro: Extreme	24 47 31	112 18 25				
	Magdalena Bay: Obs. spot (post) N. of Port Magdalena	24 38 23	112 08 54	8 25	2 12	5.5	1.5
	Cape Tosco: Extreme	24 18 12	111 42 54				
	El Conejo Point: Extreme	24 20 17	111 30 21				
	Todos Santos: Foot of hill, Lobos Pt	23 27 14	110 14 07				
	San Lucas: Steep sand beach, NW. pt. of bay	22 53 07	109 54 50				
	San José del Cabo: NE. side of entrance	23 03 35	109 40 43	8 36	2 20	4.5	1.2
	Arena Point: Extreme	23 32 48	109 28 57				
	Arena de la Ventana: Extreme	24 03 52	109 50 29				
	Pichilinque Bay: SE. pt. of San Juan, Nepomezeino I	24 15 31	110 20 34				
	La Paz: Obs. spot, El Mogote	24 10 10	110 20 41	9 40	3 34	5.4	1.3
	Lupona Point: Extreme	24 24 10	110 20 35				
	San Evaristo: 3 m. S. of S. Evaristo Hd	24 52 03	110 41 47				
	San Marcial Point: Extreme	25 29 23	111 01 43				
	Salinas Bay: Beach, NE. pt. of bay	25 59 37	111 06 53				
	Loreto: Cathedral	26 00 41	111 21 03				
	Pulpito Point: Summit	26 30 44	111 27 14				
	Muleje: Equipalito Pt	26 53 37	111 58 04				
	San Marcos Island: S. sand spit	27 10 21	112 05 39				
	Santa Maria Cove: Beach on NW. shore	27 26 06	112 19 56				
	San Carlos Point: Extreme	28 00 07	112 47 36				
	Santa Teresa Bay: Beach on N. side	28 25 04	112 51 59	11 50	5 47	11.2	2.6
	Las Animas: Low pt	28 47 40	113 12 48				
	Raza Island: Landing place, S. side	28 49 11	113 00 05				
	Angeles Bay: Bight on NW. shore	28 56 39	113 34 35				
	Remedios Bay: Beach on W. shore	29 13 52	113 40 00				
	Mejia Island: S. side	29 33 08	113 35 19				
	San Luis Island: SE. side	29 57 27	114 25 49				
	San Firmin: Beach, N. of bight	30 25 16	114 39 47				
	San Felipe Point: Peak, 1,000 feet	31 02 57	114 52 10				
	Philips Point: Beacon	31 46 10	114 43 31				
Mexico.	Georges Island: NE. shore	31 00 54	113 16 30				
	Cape Tepoca: Hill, 300 feet	30 16 05	112 53 26				
	Libertad Anchorage: Beach	29 54 12	112 45 04				
	Patos Island: SE. end	29 16 12	112 28 51				
	Tiburon Island: SE. end	28 45 55	112 21 46				
	Kino Point: 0.2 mile N. 88° W. of mound	28 45 28	111 58 37				
	San Pedro: N. side of bay	28 03 22	111 16 00				
	Guaymas: Lighthouse	27 50 28	110 54 28	11 30	5 26	5.0	1.2

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF NORTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Mexico.	Ciaris Island: NW. part	26 58 59	109 57 17				
	Santa Barbara: NW. side of bay	26 41 09	109 40 48				
	Agiabampo: SE. side of entrance	26 16 35	109 17 30				
	Topolobampo: SE. end of Santa Maria I.	25 33 56	109 10 23				
	Navachista: W. side of creek	25 23 06	108 49 00				
	Playa Colorado: N. side of entrance	25 11 42	108 23 37				
	Altata: N. side of entrance	24 38 52	107 59 37	10 07	3 59	5.8	1.4
	Mazatlan: Lighthouse	23 10 40	106 26 47	9 08	2 51	3.8	0.9
	Palenita Village: Boca Tecapan	22 30 26	105 44 25				
	San Blas: Customhouse	21 32 30	105 18 40	9 08	2 52	3.2	1.0
	Maria Madre Island: SE. extreme	21 30 45	106 33 14				
	Mita Point: Extreme	20 45 50	105 33 37				
	Peñas Anchorage: Mouth of Rio Real	20 36 26	105 16 00				
	Cape Corrientes: Extreme	20 25 00	105 39 21				
	Perula Bay. Smooth Rock	19 34 48	105 08 54	9 07	2 53	2.5	1.1
	San Benedicto Island: S. extreme	19 17 15	110 49 22				
	Socorro Island: SE. part	18 42 57	110 56 53				
	Roca Partida: Summit	18 59 41	112 04 07				
	Clarion Island: S. end	18 20 55	114 44 17				
	Clipperton Island: Summit	10 17 00	109 13 00				
	Navidad Bay: W. end of sandy beach	19 13 25	104 43 26				
	Manzanilla Bay: Flagstaff, U.S. consulate.	19 03 15	104 19 50	9 07	2 54	1.9	1.3
	Sacatula River: Beach, W. side of bay	17 58 21	102 07 06				
	Isla Grande: Tripod on NW. summit	17 40 15	101 40 25				
	Sihuatanejo Point: Tree on beach	17 37 50	101 33 23	8 50	2 38	2.0	0.9
	Morro Petatlan: Junction of stony and sandy beaches	17 31 28	101 27 14				
	Tequepa Harbor: Limekiln	17 16 13	101 04 32				
	Acapulco: Lighthouse	16 49 10	99 55 50				
	Maldonado: El Recordo Pt	16 19 37	98 35 05				
	Port Angeles: Lighthouse	15 39 09	96 30 43				
	Sacrificios Point: Highest pt. of cape	15 40 41	96 15 04				
	Port Guatulco: Cross	15 44 58	96 08 10				
	Morro Ayuca: Summit of N. edge of cape.	15 52 17	95 46 43				
	Salina Cruz: Lighthouse	16 09 36	95 12 16				
Central America.	Champerico: Inshore end of iron wharf	14 17 44	91 55 36	2 50	9 02	8.5	4.6
	San Jose de Guatemala: Lighthouse	13 55 15	90 49 45	2 50	9 02	9.0	4.9
	Acajutla: Lighthouse	13 34 20	89 50 26	2 55	9 08	9.5	5.1
	Libertad: Lighthouse	13 28 50	89 19 20	3 05	9 18	10.0	5.4
	La Union: Lighthouse	13 20 00	87 51 00	3 15	9 28	10.5	5.7
	Chicarene Point: Extreme	13 17 09	87 47 06				
	Corinto: Lighthouse	12 27 54	87 12 31	2 55	9 08	10.5	5.7
	San Juan del Sur: Signal station	11 14 45	85 53 00	3 00	9 12	10.0	5.4
	Salinas Bay: Salinas Islet	11 03 10	85 43 38	2 50	9 02	9.5	5.1
	Port Culebra: Extremity of Mala Pt	10 36 46	85 42 46	2 45	8 58	9.0	4.9
	Ballena Bay: N. Estero Toussa	9 43 45	85 00 46				
	Parida Anchorage: S. pt. of Deer Id	8 10 13	82 14 32	3 15	9 28	10.5	5.7
	Port Nuevo: Entrada Pt	8 04 30	81 43 30				
	Bahia Honda: W. end of Centinela I	7 43 32	81 31 58	3 10	9 22	11.0	5.9
	Coiba (Quibo) Island: Observation pt	7 24 20	81 41 51				
	Cocos Island: Head of Chatham Bay	5 32 57	86 59 17				
	Panama: Cathedral, S. tower	8 57 06	79 32 09	3 00	9 14	16.0	8.7
	Taboga Island: Church	8 47 45	79 33 16	3 00	9 13	15.4	8.3
	Cape Mala: Extreme	7 27 40	79 59 25	3 10	9 22	13.0	7.0
	Malpelo Island: Summit	4 03 00	81 36 00				
	Point Chamé: Extreme	8 39 00	79 41 45	3 30	9 42	15.0	8.1
	Flamenco Island: N. Pt	8 54 30	79 31 15				
	Chepillo Island: Center	8 56 32	79 07 55	3 05	9 18	16.0	8.7
	Rey Island: Cocas Pt. extreme	8 12 30	78 54 40	3 00	9 13	15.7	8.5
	Darien Harbor: Graham Pt	8 28 50	78 05 35				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

WEST INDIA ISLANDS.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Bahama Islands.	Memory Rock: Center	26 56 53	79 06 54	7 40	1 28	3.2	1.7
	Bahama Island: W. pt	26 41 18	79 00 38				
	Abaco Island: Lighthouse	25 51 30	77 10 45				
	Little Guana Cay: Lighthouse	26 31 10	76 57 36				
	Walker Cay: Highest part	27 15 42	78 23 48				
	Great Isaac Cay: Lighthouse	26 02 00	79 06 00				
	Gun Cay: Lighthouse	25 34 30	79 18 26	8 20	2 08	3.0	1.5
	Ginger Cay: Center	22 45 10	78 06 02				
	Cay Lobos: Lighthouse	22 22 30	77 34 26				
	St. Domingo Cay: Center	21 42 00	75 44 39				
	Cay Verde: Hill at S. end	22 01 15	75 10 34				
	Ragged Island: Gun Pt	22 14 02	75 45 17				
	Nairn Cay: E. pt	22 20 44	75 28 20				
	Nurse Channel Cay: Beacon	22 31 15	75 51 41				
	Long Island: S. pt	22 51 00	74 51 54				
	Great Exuma Island: Beacon	23 32 15	75 46 24				
	Clarence Harbor: Lighthouse	23 06 00	74 59 00	8 20	2 08	4.1	2.1
	Eleuthera Island: Lighthouse	25 00 00	76 13 00	7 00	0 48	4.0	2.1
	Royal Island: Eastern Pass	25 31 20	76 51 48				
	Nassau: Lighthouse	25 05 37	77 21 58	7 20	1 08	4.0	2.1
	Andros Island: Lighthouse	24 43 45	77 46 45	7 40	1 28	3.0	1.5
	Great Stirrup Cay: Lighthouse	25 49 40	77 53 55				
	Little Stirrup Cay: W. end	25 49 12	77 57 06				
	San Salvador (Cat I.): Lighthouse	24 06 15	74 26 00	7 00	0 48	4.0	2.1
	Concepcion Island: W. bay	23 50 50	75 07 27				
	Watlings Island: Hinchinbroke Rock	23 56 40	74 28 20				
	Rum Cay: Harbor Pt	23 37 45	74 50 08				
	Castle Island: Lighthouse	22 06 40	74 20 37				
	Fortune Island: S. end	22 32 40	74 22 54				
	Crooked Island: Moss flagstaff	22 47 30	74 20 21				
	Bird Island: Lighthouse	22 51 00	74 22 48				
	Samana Cay: W. pt	23 05 30	73 49 15				
	Plana Cay: NW. pt	22 34 38	73 38 03				
	Mariguana Island: SE. pt	22 16 30	72 47 03	7 20	1 08	3.0	1.5
	Hogsty Reef: NW. Cay	21 40 30	73 50 29				
	Inagua Island: Lighthouse	20 56 00	73 40 17	7 50	1 38	3.5	1.8
	Little Inagua Island: NW. pt	21 30 40	73 42 33				
	W. Caicos Cay: Hill, SE. end	21 37 30	72 28 18				
	French Cay: W. pt	21 30 00	72 12 51				
	Fort George Cay: Old magazine	21 54 00	72 07 14				
	Caicos Island: Parsons Pt., S. islet	21 29 33	71 31 12				
	Turk Island: Lighthouse	21 30 55	71 07 29	7 30	1 18	3.0	1.5
	Square Handkerchief Bank: NE. breaker	21 06 30	70 29 54				
	Silver Bank: E. extreme	20 35 00	69 21 24				
	Navidad Bank: Center of E. side	20 02 00	68 47 24				
Cuba.	Cape Maysi: Lighthouse	20 15 00	74 08 01	5 40	11 53	2.8	1.6
	Port Baracoa: Lighthouse	20 21 46	74 29 13				
	Port Cayo Moa: Carenero Pt	20 41 41	74 53 44				
	Nipe Bay: Extremity of Carenero Pt	20 47 19	75 34 21				
	Lucrecia Point: Lighthouse	21 04 24	75 36 59				
	Port Sama: E. side of entrance	21 09 00	75 47 18				
	Peak of Sama: Summit, 885 feet	21 07 00	75 47 40				
	Port Naranjo: E. side of entrance	21 07 30	75 52 18				
	Gibara: Lighthouse	21 07 15	76 06 27	6 20	0 08	2.4	1.4
	Port Padre: Guinchos Pt	21 18 30	76 35 34				
	Port Nuevitas: NW. corner R. R. station	21 32 44	77 15 18	7 00	0 48	2.2	1.2
	Maternillos Point: Lighthouse	21 40 02	77 08 04				
	Cay Verde: NW. end	22 08 45	77 37 33				
	Cay Confites: S. pt	22 11 14	77 39 23				
	Paredon Grande Cay: Lighthouse	22 29 10	78 09 11	7 20	1 08	2.8	1.6
	San Fernando: NW. corner Old Spanish Fort No. 1	22 09 44	78 35 54				
	Cayo Frances: Lighthouse	22 38 41	79 13 44				

MARITIME POSITIONS AND TIDAL DATA.

WEST INDIA ISLANDS—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Cuba.	Isabella de Sagua: SE. corner of church	22 56 30	80 00 32				
	Cay Sal: Lighthouse	23 56 30	80 27 51				
	Bahia de Cadiz Cay: Lighthouse	23 12 34	80 29 26				
	Piedras Cay: Lighthouse	23 14 10	81 07 20				
	Cardenas: Cross on Cathedral	23 02 43	81 12 02				
	Matanzas: Summit of peak	23 01 54	81 43 18	8 30	2 18	2.2	1.2
	Habana: Morro lighthouse	23 09 26	82 21 29	8 18	1 56	1.3	0.7
	Transit pier, Casa Blanca Observatory	23 09 04	82 20 38				
	Flagstaff, Cabañas Fortress	23 09 11	82 21 01				
	Bahia Honda: SE. corner Morillo Fort	22 59 11	83 09 13				
	Gobernadora Pt.: Lighthouse	23 00 00	83 13 00				
	Dimas: NW. corner of warehouse	22 29 32	84 14 17				
	Cape San Antonio: Lighthouse	21 52 01	84 57 09	8 30	2. 18	1.5	0.9
	Radio tower	21 53 55	84 56 16				
	La Caloma: SW. corner of warehouse	22 14 36	83 34 24				
	San Felipe Cays: SW. pt	21 55 00	83 31 18				
	Isla de Pinos: Port Frances	21 35 30	83 09 13				
	Batabano: Lighthouse	22 41 09	82 17 42				
	Piedras Cay: Lighthouse	21 57 45	81 07 18				
	Cienfuegos: Colorados Pt. light	22 01 49	80 26 32	4 47	11 00	2.0	1.1
	Cathedral tower	22 08 36	80 27 05				
	Flagstaff, Punta Gorda	22 06 52	80 27 11				
	Casilda: Observation pier	21 48 16	79 58 58				
	Jucaro: Observation pier	21 37 24	78 51 13				
	Santa Cruz del Sur: Observation pier	20 42 23	77 59 45				
	Manzanillo: Observation pier	20 20 26	77 07 33				
	Niquero: Sugar mill, smokestack	20 02 55	77 34 50				
	Cape Cruz: Lighthouse	19 50 32	77 43 33				
	Point Mota	19 53 31					
	Chirivico: Damas Cay	19 56 57					
	Santiago: Lighthouse	19 57 29	75 52 03	8 20	2 30	2.2	1.1
	Guantanamo Bay: Fisherman Pt	19 54 42	75 09 28	7 50	2 00	2.6	1.3
	Lighthouse	19 53 04	75 09 28				
	Naval Station flagstaff	19 57 00	75 07 33				
	Port Escondido: Inner Entrance Pt	19 54 08	75 03 08				
	Port Baitiqueri: Barlovento Pt	20 01 01	74 50 49				
	Cayman Brac: E. pt	19 45 15	79 46 07				
	Little Cayman: W. pt	19 39 10	80 07 17				
	Grand Cayman: Fort George, W. end	19 17 45	81 23 17			[1.3]	
Jamaica.	Formigas Bank: Shoal spot	18 33 00	75 44 24				
	Morant Point: Lighthouse	17 55 05	76 11 08			[1.1]	
	Port Antonio: Folly Pt. Light	18 11 31	76 26 31				
	Port Maria: NW. wharf	18 23 00	76 54 22				
	St. Ann Bay: Long wharf	18 26 24	77 12 52			[1.2]	
	Falmouth: Fort	18 30 34	77 39 52				
	Montego Bay: Fort	18 29 25	77 56 16				
	St. Lucia: Fort	18 27 45	78 10 52				
	Savanna-la-Mar: Fort	18 12 20	78 08 54				
	Kingston: Port Royal flagstaff	17 55 56	76 50 35				
	Port Royal: Fort Charles, flagstaff	17 55 56	76 50 38			[1.1]	
Isl. of Haiti.	Morant Cays: NE. Cay	17 26 30	75 58 20				
	Pedro Bank: Portland Rock, E. end	17 06 20	77 26 28				
	Baxo Nuevo: Sandy Cay	15 53 00	78 39 04				
	Cape Engano: Extreme	18 35 52	68 18 50				
	Samana Town: Obs. spot	19 12 29	69 19 23	9 00	2 48	3.0	1.5
	Cape Cabron: East extreme	19 22 12	69 12 12				
	Port Plata: Lighthouse	19 48 51	70 41 27				
	Monte Cristi: Cabra Island	19 54 00	71 40 15				
	Manzanillo Point	19 46 20	71 46 40	6 50	0 39	5.5	2.9
	Cape Haitien: Town fountain	19 46 19	72 12 07				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

WEST INDIA ISLANDS—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Island of Haiti.	Port Paix: Wharf	19 57 06	72 50 00				
	St. Nicholas Mole: Fort George, flagstaff	19 49 15	73 23 07				
	Gonaives: Verreur Pt	19 27 12	72 43 52				
	Gonave Island: W. pt	18 56 00	73 18 20				
	Arcadins Islands: Lighthouse	18 48 50	72 39 13				
	Port au Prince: Fort Islet light	18 33 31	72 21 00			[1. 2]	
	Jeremie: Fort	18 39 15	74 06 52				
	Cape Dame Marie: Extreme	18 36 48	74 25 50				
	Navassa Island: NW. extreme	18 25 00	75 01 57				
	Aux Cayes: Tourterelle Bat'y	18 11 08	73 44 08				
	Jacmel: Wharf	18 13 25	72 30 45			[2. 5]	
	False Cape: Extreme	17 46 08	71 41 06				
	Beata Island: NW. pt	17 36 55	71 31 10				
	Fraile Rock: Center	17 37 37	71 41 10				
	Alta Vela: Summit	17 28 22	71 38 30				
	Avarena Point: Extreme	18 08 55	71 02 25				
	Salinas Point (Caldera): Extreme	18 12 13	70 32 53				
	Sto. Domingo City: Lighthouse	18 27 54	69 52 59			[2. 2]	
	Saona Island: Pt. Catuano	18 11 57	68 45 41				
Porto Rico.	Mona Island: Lighthouse	18 05 17	67 50 50				
	Mayaguez: Mouth of Mayaguez R	18 12 37	67 09 17	7 04	2 00	2. 0	1. 0
	Aguadilla: Columbus Monument	18 24 51	67 09 42				
	San Juan: Morro lighthouse	18 28 23	66 07 26	8 21	2 20	1. 3	0. 9
	Cape San Juan: Lighthouse	18 23 01	65 37 07				
	Guanica: Meseta Pt. lighthouse	17 57 10	66 54 13			[1. 0]	
	Culebrita Island: Lighthouse	18 18 56	65 13 40	[7 31]	[1 30]	[1. 0]	
	Vieques (Crab) Island: Port Ferro light	18 05 54	65 25 26	[7 35]	[1 40]	[1. 1]	
	St. Thomas: Fort Christian, SW. bastion	18 20 23	64 55 47	[7 11]	[0 58]	[1. 2]	
	St. John Island: Ram Head	18 18 08	64 42 03				
	Tortola: Fort Burt	18 25 04	64 36 47				
	Virgin Gorda: Vixen Pt	18 30 39	64 21 48				
	Anegada: W. pt	18 45 11	64 24 58				
	E. extreme of reefs	18 36 30	64 10 45				
	St. Croix, Christiansted: SW. bastion of fort	17 45 09	64 42 16				
	St. Croix, Lang's Observatory	17 44 43	64 41 14				
	Sombrero: Lighthouse	18 35 37	63 28 13				
	Dog Island: Center	18 16 42	63 16 00				
	Anguilla: Customhouse	18 13 06	63 04 39				
	St. Martin: Fort Marigot light	18 04 07	63 05 45				
	St. Bartholomew: Fort Oscar	17 53 58	62 51 30			[1. 5]	
	Saba: Diamond Rock	17 39 10	63 15 16				
	St. Eustatius: Fort flagstaff	17 29 10	62 59 09				
	St. Christopher: Basseterre Church	17 18 12	62 43 14				
	Booby Island: Center	17 13 38	62 35 25				
	Nevis: Fort Charles	17 07 52	62 37 29				
	Barbuda: Flagstaff, Martello Tower	17 35 50	61 49 54				
	Antigua, English Harbor: Flagstaff, dock-yard	17 00 00	61 46 07			[2. 0]	
	Sandy Island: Lighthouse	17 06 54	61 55 11				
	Redonda Islet: Center	16 55 18	62 19 10				
	Montserrat: Plymouth Wharf	16 42 12	62 13 24				
	Guadeloupe, Basseterre: Light on mast	15 59 50	61 44 09				
	Port Louis: Light on mast	16 25 09	61 32 15				
	Gozier Islet: Lighthouse	16 11 57	61 29 40			[1. 3]	
	Manroux Id.: Lighthouse	16 13 14	61 32 05				
	Point a Pitre: Jarry Mill	16 13 56	61 33 15				
	Desirade: E. pt	16 19 56	61 00 44				
	Petite Terre: Lighthouse	16 10 17	61 06 45				
	Marie Galante: Lighthouse	15 52 59	61 19 15				
	Saintes Islands: Tower on Chameau Hill	15 51 32	61 35 55				

MARITIME POSITIONS AND TIDAL DATA.

WEST INDIA ISLANDS—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Dominica, Prince Ruperts Bay: Sand beach W. of church	15 34 34	61 28 14	4 00	10 12	1.5	0.8
	Roseau: Flagstaff, Fort Young	15 17 27	61 23 52				
	Aves Island: Center	15 42 00	63 37 46				
	Martinique, Fort de France: Fort St. Louis light	14 35 44	61 04 30				
	St. Pierre: Ste. Marthe Battery	14 43 54	61 11 09				
	Caravelle Pen.: Lighthouse	14 46 13	60 53 20	3 50	10 02	1.1	0.6
	Cabrit Islet: Summit	14 23 23	60 52 33				
	St. Lucia, Port Castries: Lighthouse	14 01 54	61 00 48				
	Barbados, Bridgetown: Flagstaff, Rickett's Battery	13 05 43	59 37 16	2 50	9 02	3.0	1.5
	S. Point: Lighthouse	13 02 45	59 31 50				
	Ragged Point: Lighthouse	13 09 40	59 26 04				
	St. Vincent, Kingstown: Lighthouse	13 09 19	61 14 34	2 50	9 05	1.6	0.8
	Bequia Island, Admiralty Bay: Church	13 00 25	61 14 09				
	Grenada: St. George Lighthouse	12 03 02	61 45 06	2 30	8 42	1.5	0.8
	Tobago, Rocky Bay: Lighthouse	11 10 08	60 42 38	3 50	10 02	2.1	1.1
	Testigos Islets: Center of Testigo Grande	11 25 02	63 05 48				
	Sola Island: Center	11 19 00	63 36 00				
	Pampatar, Margarita I.: San Carlos Castle	10 59 43	63 48 00				
	Tortugas Island: S. end of W. Tortugillo Islet	10 57 45	65 26 38				
	Orchila Island: S. side	11 47 57	66 12 31				
	Roques Islands: Pirate Cay	11 56 16	66 39 10				
	Bonaire Island: Lighthouse	12 02 06	68 14 10				
	Little Curaçao Island: Lighthouse	11 59 30	68 39 19				
	Curaçao Island: Fort Nassau	12 06 58	68 55 48				
	Lighthouse	12 06 15	68 56 17				
	Oruba Island: Lighthouse	12 31 05	70 02 34				

NORTH AND EAST COASTS OF SOUTH AMERICA.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
Colombia.	Caribana Point: Extreme	8 37 30	76 52 55				
	Fuerte Island: N. extreme	9 24 00	76 10 45				
	Cispata Port: Zapote Pt	9 24 00	75 48 00				
	Cartagena: Lighthouse	10 25 50	75 32 50				
	Savanilla: Lighthouse	11 00 15	74 57 55				
	Magdalena River: NW. pt. of Gomez I	11 07 00	74 49 51				
	Santa Marta: Lighthouse	11 15 28	74 14 33				
	Rio de la Hacha: Light on church	11 33 30	72 54 50				
	Cape La Vela: Sand beach inside cape	12 12 34	72 09 42				
	Bahia Honda: E. pt., S. side	12 23 09	71 45 42				
Venezuela.	Espada Point: Extreme	12 04 00	71 07 55				
	Maracaibo: Zapara I. light	10 57 30	71 37 00	5 05	11 17	2.5	1.5
	Estangues Point: 500 ft. from extreme	11 48 56	70 17 21				
	Cape San Roman: Extreme	12 11 00	70 04 55				
	Marjes Islets: N. islet	12 29 15	70 57 00				
	Vela de Coro: Lighthouse	11 27 56	69 34 20				
	Tucacas Island: Ore house	10 47 00	68 19 55				
	St. Juan Bay: Cay	11 10 00	68 22 54				
	Puerto Cabello: Lighthouse	10 29 53	68 00 55				
	La Guaira: Lighthouse	10 36 57	66 56 06	6 00	12 12	2.8	1.7
	Cape Codera: Morro	10 35 00	66 06 15				
	Corsarios Bay: W. pt	10 34 06	66 04 13				
	Centinela Islet: Center	10 49 30	66 09 25				
	Barcelona: Morro	10 13 30	64 44 00				
	Cumana: Lighthouse	10 27 20	64 11 33				
	Escarceo Point: Extreme	10 40 00	64 17 55				
	Chacopata: Morro	10 42 00	63 50 25				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

NORTH AND EAST COASTS OF SOUTH AMERICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Venezuela.	Esmeralda Islet: Center	10 40 00	63 31 55				
	Carupano: Lighthouse	10 40 15	63 18 00				
	Pt. Herman Vasquez	10 42 00	63 14 00				
	Puerto Santo Bay: Sand spit S. of Morro	10 43 27	63 09 43				
	Tres Puntas Cape: Extreme	10 45 00	62 41 55				
	Unare Bay: Obs. spot, 200 yds. S. of Morro	10 44 19	62 44 29				
	Pena Point: Extreme	10 43 48	61 50 50				
	Pato Island: E. pt	10 38 15	61 51 18				
	Mocomoco Pt.: Extreme	8 39 25	60 10 15				
Trinidad.	Port of Spain: King's Wharf light	10 38 37	61 30 35	4 20	10 30	3.2	1.9
	Chacachacare Island: Rocks off SW. pt.	10 40 03	61 45 54				
	Galera Point: NE. extreme, lighthouse	10 50 02	60 54 10				
	Icacos Point: Lighthouse	10 03 29	61 55 41				
	San Fernando: Pierhead	10 16 59	61 28 12				
Guiana.	Demerara: Georgetown lighthouse	6 49 20	58 11 30	4 18	9 50	8.6	3.9
	Nickerie River: Lighthouse	5 58 30	57 00 30				
	Paramaribo: Stone steps	5 49 30	55 08 48	5 50	12 00	9.5	4.3
	Maroni River: W. lighthouse	5 44 50	54 00 30				
	Salut Islands: Lighthouse	5 16 50	52 34 53				
	Enfant Perdu Islet: Lighthouse	5 02 40	52 21 11				
	Cayenne: Lighthouse	4 56 20	52 20 26	4 27	10 30	6.0	2.7
	Connetable Islet: Center	4 49 30	51 55 36				
	Carimare Mount: Summit	4 23 20	51 50 36				
Brazil.	Orange Cape: Extreme	4 20 45	51 27 46				
	Maye Mountain: Summit	2 46 30	50 54 46				
	North Cape: Extreme	1 40 17	49 56 46				
		Lat. S.					
	Cape Magoari: Extreme	0 17 00	48 23 30				
	Para: Customhouse	1 26 59	48 30 01	11 50	5 37	11.0	5.2
	Atalaia Point: Lighthouse	0 35 03	47 20 54				
	Itacolomi Point: Lighthouse	2 10 11	44 25 56				
	Maranhao Island: Landing place	2 31 48	44 18 45	6 50	0 38	16.5	7.9
	Santa Anna Island: Lighthouse	2 16 22	43 37 30	5 35	11 47	13.1	6.2
	Tutoya: Entrance	2 41 55	42 18 02	5 05	11 17	11.7	5.6
	Paranahiba River: Amarçao Village	2 53 20	41 40 35				
	Ceara: Lighthouse	3 42 05	38 28 25	5 25	11 37	8.2	3.9
	Jaguaribe River: Pilot station	4 25 35	37 44 55	5 50	12 00	8.0	3.8
	Caiçara: Village	5 03 15	36 02 52				
	Cape St. Roque: Extreme	5 29 15	35 15 52	4 05	10 17	8.8	4.2
	Rio Grande do Norte: Lighthouse	5 45 05	35 11 55				
	Natal: Cathedral	5 46 41	35 12 43				
	Parahiba River: Lighthouse at entrance	6 56 30	34 49 30				
	Parahiba: Cathedral	7 06 35	34 53 04				
	Olinda: Lighthouse	8 00 50	34 50 36				
	Pernambuco: Picao lighthouse	8 03 22	34 51 57	4 33	10 50	7.0	3.3
	Cape St. Augustine: Lighthouse	8 20 45	34 56 05				
	Tamandare: Village	8 43 40	35 05 06				
	Maceio: Lighthouse	9 39 35	35 44 54	4 20	10 32	8.5	4.1
	San Francisco River: Lighthouse at entrance	10 30 30	36 21 51	4 17	10 29	7.8	3.7
	Cotinguiba River: Lighthouse at entrance	10 58 20	37 04 00				
	Vaza Barris River: Semaphore at entrance	11 09 45	37 12 36				
	Real River: Lighthouse	11 27 40	37 24 00				
	Conde: Village	12 12 05	37 45 46				
	Garcia d'Avila: Tower	12 33 40	38 02 16				
	Bahia: Santo Antonio lighthouse	13 00 37	38 32 06	4 10	10 22	7.6	3.6
	Itaparica: Fort on N. pt	12 52 48	38 41 28				
	Morro de São Paulo: Lighthouse	13 22 37	38 54 38	3 50	10 00	6.0	2.9
	Camamu: Village	13 56 42	39 07 05	3 50	10 00	6.3	3.0
	Contas: Church	14 17 40	39 00 45				

MARITIME POSITIONS AND TIDAL DATA.

NORTH AND EAST COASTS OF SOUTH AMERICA—Continued.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Brazil.	Ilheos: Church	14 47 40	39 03 25	3 35	9 47	6.4	3.1
	Olivença: Center of village	14 56 40	39 01 45				
	Una: Center of village	15 13 27	39 01 15				
	Comandatuba: Center of village	15 21 00	39 16 45				
	Santa Cruz: Church	16 17 20	39 02 05	3 25	9 37	6.0	2.9
	Porto Seguro: Matriz Church	16 25 38	39 04 15				
	Prado: River entrance	17 21 40	39 13 15				
	Alcobaça: Center of village	17 31 45	39 12 00				
	Caravellas: Center of village	17 43 30	39 14 36	3 10	9 23	6.4	3.1
	Abrolhos Island: Lighthouse	17 57 31	38 41 46	3 15	9 27	7.5	3.6
	Porto Alegre: Center of village	18 06 15	39 31 16				
	Espiritu Santo Bay: Lighthouse	20 19 23	40 16 36	2 50	9 00	4.0	1.9
	Guarapiri Islets: E. islet	20 38 25	40 23 46				
	Benevente: Village	20 49 00	40 40 45	2 40	8 52	5.0	2.4
	Itapemirim: Moscas Islet	20 57 35	40 46 35				
	São João da Barra: Lighthouse	21 38 40	41 02 21				
	Cape St. Thomé: Extreme	22 02 00	40 59 00				
	Macahé: Fort at entrance	22 23 45	41 47 35	2 20	8 30	9.2	4.4
	Santa Anna Island: Summit	22 26 00	41 43 15				
	Barra São João: Village	22 37 00	41 59 45				
	Busios: Church	22 46 00	41 54 05				
	Cape Frio: Lighthouse	23 00 42	42 00 00				
	Port Frio: Village	22 53 15	42 01 15	2 30	8 42	4.9	2.3
	Maricas Islands: S. islet	23 01 43	42 54 05				
	Rio de Janeiro: Fort Villegagnon Light	22 54 46	43 09 19	2 50	9 00	4.2	2.0
	National Observatory	22 54 24	43 10 21				
	Raza Island: Lighthouse	23 03 40	43 08 45				
	Petropolis: Center of town	22 32 00	43 11 01				
	Cape Guaratiba: Summit	23 03 40	43 33 24				
	Marambaya Island: Summit of SW. end	23 04 20	43 59 26				
	Mangaratiba: Village	22 57 20	44 02 29				
	Palmas Bay: Beach at head of bay	23 09 20	44 08 24				
	Angra dos Reis: Landing place	23 00 30	44 19 04				
	Ilha Grande: Lighthouse	23 09 50	44 05 45				
	Parati: Fort	23 12 20	44 42 04	1 35	7 47	5.3	2.5
	Ubatuba: Cathedral	23 25 55	45 04 04				
	Porcos Grande Islet: Summit	23 32 57	45 03 50				
	Busios Islets: Summit	23 45 15	45 00 39				
	St. Sebastian Island: Boi Pt. light	23 58 30	45 15 20				
	Villa Nova da Princessa: Center	23 47 20	45 21 04				
	Santos: Moela I. lighthouse	24 03 06	46 15 57				
	Quay	23 56 00	46 19 09	2 50	9 00	5.0	2.8
	Alcatrazes Island: Summit, 880 ft	24 06 30	45 40 49				
	Conceição: Church	24 10 32	46 47 44				
	Quemada Grande Island: Summit, 623 ft.	24 28 45	46 41 04				
	Iguape: Quay	24 42 35	47 32 54				
	Bom Abrigo Islet: Lighthouse	25 06 40	47 51 50				
	Ilha do Mel: Lighthouse	25 30 55	48 19 53				
	Paranagua: Quay	25 31 20	48 31 03	2 55	9 05	6.4	3.1
	Antonina: Quay	25 26 30	48 43 14				
	Coral Islet: Center	25 44 10	48 23 14				
	Itacolomi Islet: Center	25 50 15	48 25 51				
	São Francisco: Center of town	26 14 17	48 39 29				
	Itapacaroya: Church	26 46 45	48 36 59				
	Cambria: Church	27 01 35	48 36 44				
	Arvoredo Island: Lighthouse	27 18 00	48 22 20				
	Anhatomirim: Lighthouse	27 25 30	48 34 25				
	Sta. Catherina Island: Rapa Pt	27 22 55	48 26 09	2 35	8 47	5.9	2.8
	Naufragados light	27 50 27	48 35 16				
	Nossa Senhora do Deserto: Quay	27 36 00	48 34 14				
	Coral Island: Summit, 230 feet	27 56 40	48 33 44				
	Cape St. Martha: Lighthouse	28 38 00	48 49 45				
	Torres Point: Extreme	29 20 20	49 43 39				
	Rio Grande do Sul: Lighthouse	32 06 40	52 07 44	4 00	10 12	1.8	0.9

MARITIME POSITIONS AND TIDAL DATA.

NORTH AND EAST COASTS OF SOUTH AMERICA—Continued.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Uruguay.	Castillos: Beuna Vista Hill, 184 feet	34 21 19	53 47 16	8 20	2 08	2.0	0.9
	Cape Santa Maria: Lighthouse	34 40 01	54 09 14				
	Lobos Island: Center	35 01 39	54 53 16				
	Maldonado: Lighthouse	34 58 15	54 57 10				
	Flores Island: Lighthouse	34 56 55	55 55 04				
	Montevideo: Cathedral, SE. tower	34 54 33	56 12 15	2 00	8 12	3.5	2.3
	Colonia: Lighthouse	34 28 20	57 52 27	6 30	0 00	4.0	2.7
Argentina.	Martin Garcia Island: Lighthouse	34 10 50	58 15 40				
	Buenos Ayres: Cupola of customhouse	34 36 30	58 22 14	6 43	12 15	2.1	1.4
	La Plata: National University Obsy	34 54 30	57 54 15				
	Indio Point: Lighthouse	35 15 45	57 10 45				
	Piedras Point: Extreme	35 26 50	57 05 28				
	Cape San Antonio: Lighthouse	36 18 24	56 44 15	9 50	3 35	5.3	3.5
	Madanas Point: Lighthouse	36 53 00	56 38 54				
	Cape Corrientes: E. summit	38 05 30	57 30 01				
	Port Belgrano: Anchor-Stock Hill	38 57 00	61 59 15	6 00	0 00	15.8	8.2
	Argentina: Fort	38 43 50	62 15 27				
	Labyrinth Head: Summit	39 26 30	62 03 22				
	Union Bay: Indian Head	39 57 30	62 07 46				
	San Blas Harbor: SW. end of Hog Islet	40 32 52	62 09 30				
	San Blas Bay: Summit of Rubia Pt.	40 36 10	62 10 12				
	Rio Negro: Main Pt	41 02 00	62 45 11	10 50	4 38	14.7	7.7
	Bermeja Head: E. summit	41 11 00	63 08 16				
	Port San Antonio: Point Villarino	40 49 00	64 54 41	10 35	4 23	23.5	12.3
	San Antonio Sierra: Summit	41 41 10	65 12 29				
	Port San Jose: San Quiroga Pt	42 14 15	64 27 56				
	Delgado Point: SE. cliff	42 46 15	63 37 16				
	Cracker Bay: Anchorage	42 57 00	64 28 20				
	Port Madryn: Anchorage off cave bluff	42 45 40	64 59 00	7 05	0 52	13.2	6.9
	Chupat River: Entrance	43 20 45	65 03 36				
	Port St. Elena: St. Elena pen	44 30 40	65 22 10	3 50	10 03	16.8	8.8
	Leones Island: SE. summit	45 04 00	65 36 01				
	Melo Port: W. pt	45 03 00	65 52 30				
	Port Malaspina: S. pt	45 10 10	66 32 36				
	Cape Three Points: NE. pitch	47 06 20	65 51 46				
	Port Desire: Largest ruin	47 45 05	65 54 45	0 00	6 12	18.3	9.6
	Sea Bear Bay: Wells Pt	47 57 15	65 45 40				
	Port San Julian: Sholl Pt	49 15 20	67 42 30	10 35	4 23	29.5	15.4
	Port Santa Cruz: Mount at entrance	50 08 30	68 23 00	9 20	3 08	39.6	20.7
	Coy Inlet: Height S. side of entrance	50 58 27	69 09 47	9 00	2 47	40.0	20.9
	Gallegos River: Observation mound	51 33 21	69 00 31	8 40	2 28	45.6	23.9
	Cape Virgins: SE. extreme	52 18 35	68 22 12	8 18	2 06	38.7	20.2
	Cape San Diego: Extreme	54 40 35	65 05 53	4 20	10 33	9.9	5.2
	Staten Island, Cape St. John: Lighthouse, W. pt	54 43 24	63 47 00	4 19	10 32	7.8	6.0
	Port Cork: Observation mark, summit	54 45 16	64 03 00				
	Cape St. Bartholomew: Middle pt	54 53 45	64 45 45				
	Good Success Bay: S. end of beach	54 48 02	65 13 48				
Chile.	Lennox Cove: Bluff, N. end of beach	55 17 00	66 49 00				
	Goree Road: Guanaco Pt	55 19 00	67 10 00	3 50	10 03	6.7	5.2
	Wollaston Island: Middle Cove	55 35 30	67 19 00				
	Barneveldt Islands: Center	55 48 54	66 43 48				
	Cape Horn: South summit, 1,391 ft	55 58 41	67 16 15				
	Hermite Island: St. Martin Cove	55 51 20	67 34 00	4 07	10 02	4.8	3.8
	False Cape Horn: S. extreme	55 43 15	68 04 40				
	Ildefonso Islands: Highest summit	55 52 30	69 17 30				
	Diego Ramirez Island: Highest summit	56 28 50	68 41 30	3 50	10 03	5.0	3.9
	York Minster Rock: Summit, 800 ft	55 24 50	70 01 30				
	Cape Desolation: S. summit	54 45 40	71 36 10				
	Mount Skyring: Summit, 3,000 ft	54 24 48	72 10 20				

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF SOUTH AMERICA.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Chile.	Noir Island: SE. extreme	54 30 00	73 00 00	2 20	8 33	4.8	3.7
	Landfall Island: Summit of Cape Inman	53 18 30	74 18 15	1 50	8 03	4.7	3.7
	Cape Deseado: Peaked summit	52 55 30	74 36 30				
	Apostle Rocks: W. rocks	52 46 15	74 46 50				
	Cape Pillar: N. cliff	52 42 50	74 42 20	0.32	6 45	4.0	3.1
	Dungeness Point: Lighthouse	52 23 55	68 25 45	8 19	2 07	39.4	20.6
	Cape Espiritu Santo: NE. cliff	52 39 00	68 34 00	8 20	2 08	39.0	20.4
	Catharine Point: NE. extreme	52 32 00	68 45 20	8 24	2 12	30.0	15.7
	Cape Possession: Lighthouse	52 17 54	68 57 10	8 35	2 25	39.0	20.4
	Cape Orange: N. extreme	52 28 40	69 24 00				
	Delgada Point: Lighthouse	52 28 00	69 33 00	8 47	2 40	39.0	20.4
	Cape Gregory: Lighthouse	52 38 18	70 14 16	9 23	3 20	21.0	11.0
	Cape St. Vincent: W. extreme	52 46 20	70 25 25				
	Elizabeth Island: NE. bluff	52 49 18	70 37 51	10 24	4 24	8.0	4.2
	Sandy Point: Lighthouse	53 10 10	70 54 24	11 03	5 03	5.0	2.6
	Cape St. Valentine: Summit, at extreme	53 33 30	70 34 27				
	Port Famine: Observatory	53 38 12	70 58 31	11 58	5 58	6.0	3.1
	Cape San Isidro: Extreme	53 47 00	70 55 03	12 21	6 21	8.0	4.2
	Cape Froward: Summit of bluff	53 53 43	71 17 15	0 28	6 53	7.0	3.7
	Mount Pond: Summit	53 51 45	71 55 30				
	Port Gallant: Wigwam Pt	53 41 45	71 59 41	1 20	7 40	8.0	4.2
	Charles Island: White rock near NW. end	53 43 57	72 04 45				
	Rupert Island: Summit	53 42 00	72 10 42				
	Mussel Bay: Entrance	53 37 10	72 19 30				
	Tilly Bay: Sarah I	53 34 20	72 27 10				
	Borja Bay: Bluff on W. shore	53 31 45	72 34 15	1 54	8 11	5.5	2.9
	Cape Quod: Extreme	53 32 10	72 32 25				
	Barcelo Bay. Entrance	53 30 50	72 38 00				
	Swallow Bay: Shag I	53 30 05.	72 47 30	1 53	8 08	5.0	3.9
	Cape Notch: Extreme	53 25 00	72 47 55				
	Playa Parda Cove: Summit of Shelter I.	53 18 45	73 00 30	1 31	7 44	4.5	3.5
	Pollard Cove: Entrance	53 15 30	73 12 05				
	Port Angosto: Hay Pt	53 13 40	73 21 30	1 09	7 21	4.0	3.1
	St. Anne Island: Central summit	53 06 30	73 15 30				
	Half Port Bay: Point	53 11 40	73 17 45				
	Upright Port: Entrance	53 06 35	73 16 15				
	Port Tamar: Mouat Islet	52 55 46	73 44 28	0.55	7 07	6.0	4.6
	Port Churruca: Summit of Blanca Pen.	53 01 00	73 59 33				
	Valentine Harbor: Observation mount	52 55 00	74 17 45				
	Cape Parker: W. summit	52 42 00	74 13 30				
	Mercy Harbor: Summit of Battle I	52 44 58	74 38 14				
	Mayne Harbor: Observation spot	51 18 29	74 04 00				
	Port Grappler: Observation spot	49 25 19	74 17 39				
	Port Riofrio: Vitalia I	49 12 40	74 23 27				
	Eden Harbor: Observation spot	49 07 30	74 25 10				
	Halt Bay: Observation islet	48 54 20	74 20 55				
	Westminster Hall Islet: E. summit	52 37 18	74 23 10				
	Evangelistas Island: Lighthouse	52 24 00	75 06 00	0 55	7 08	4.4	3.4
	Cape Victory: Extreme	52 16 10	74 55 00				
	Cape Isabel: W. extreme	51 51 50	75 13 20				
	Cape Santiago: Summit	50 42 00	75 27 45				
	Molyneux Sound: Romalo I	50 17 20	74 51 30				
	Cape Tres Puntas: Summit, 2,000 ft	50 02 00	75 22 00				
	Port Henry: Observation spot	50 00 18	75 13 20	0.30	6 45	4.5	3.5
	Mount Corso: SW. summit	49 48 00	75 34 00				
	Rock of Dundee: Summit	48 06 15	75 40 30				
	Santa Barbara Port: N. extreme obs. pt.	48 02 20	75 28 20	0 15	6.30	5.3	4.1
	Guaineco Islands: Speedwell Bay, hill, NE. pt	47 39 30	75 10 00				
	Port Otway: Observation spot	46 49 31	75 18 20	0 10	6 25	5.3	4.1
	Cape Tres Montes: Extreme	46 58 57	75 25 30				
	Cape Raper: Rock close to cape	46 49 10	75 37 55				
	Christmas Cove: SE. extreme	46 35 00	75 31 30				
	Hellyer Rocks: Middle	46 04 00	75 12 00				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF SOUTH AMERICA—Continued.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Chile.	Cape Taytao: W. extreme	45 53 20	75 06 00	0 00	6 13	4.4	3.4
	Socorro Island: S. extreme	44 55 50	75 08 45				
	Mayne Mountain: Summit, 2,080 ft	44 09 00	74 07 45				
	Port Low: Huacanec I., S. end	43 49 15	74 00 30	0 15	6 10		
	Guafo Island: S. extreme	43 43 05	74 42 15	12 10	6 00	6.1	3.1
	Port San Pedro: Cove on S. shore	43 19 30	73 42 25				
	Cape Quilan: SW. extreme	43 16 25	74 24 15				
	Corcovado Volcano: Summit, 7,527 ft	43 11 30	72 48 30				
	Minchinmadiva Volcano: S. summit, 8,000 feet	42 46 45	72 31 25				
	Castro: Extreme of point	42 29 15	73 45 05	0 01	6 21	18.0	9.1
	Dalcahue: Chapel	42 22 45	73 38 10				
	Comau Inlet: Morro Comau	42 11 15	72 35 55				
	Port Montt: Lt. on end of pier	41 28 36	72 56 15	0 31		21.0	14.5
	Port Calbuco: La Picuta	41 46 20	73 07 55	1 10	7 35	14.8	7.5
	Ancud: Ahui Pt. light	41 49 58	73 51 12	0 04	6 20	5.9	3.0
	Condor Cove: Landing	40 46 19	73 51 00				
	Ranu Cove: Anchorage	40 43 18	73 49 50				
	Muilcalpue Cove: Landing place	40 35 52	73 45 00				
	Milagro Cove: Landing place	40 21 04	73 45 20				
	Laruehuapi Cove: Landing place	40 11 47	73 41 50	0 00	6 13	7.2	3.7
	Valdivia: Niebla Fort light	39 51 37	73 26 25	10 25	4 13	5.6	2.8
	Queule Bay: Choros Pt.	39 23 00	73 14 00	10 18	4 05	4.9	2.5
	Mocha Island: Lighthouse	38 21 22	73 58 06	10 20	5 07	3.3	1.7
	Lebu River: Tucapel Head	37 35 20	73 39 55	10 15	4 02	4.9	2.5
	Yañez Port: Anchorage	37 22 30	73 40 00	10 10	3 55	5.3	2.7
	Lota: Lighthouse	37 05 20	73 11 13	10 05	3 50	4.9	2.5
	Santa Maria Island: Lighthouse	36 59 07	73 32 30	10 10	3 55	6.0	3.0
	Talcahuano: Fort Galvez	36 42 00	73 07 27	10 04	3 51	5.3	2.7
	Light on Quinquina I.	36 36 45	73 02 49	10 05	3 53	5.0	2.5
	Llico: Village	34 46 02	72 06 12	9 57	3 48	4.1	2.1
	Port San Antonio: Village	33 34 13	71 38 00	9 44	3 34	4.0	2.0
	Aconcagua Mountain: Summit	33 38 30	69 56 30				
	Santiago: Observatory	33 26 42	70 41 32				
	Valparaiso: Playa Ancha Pt. light	33 01 08	71 38 52	9 37	3 26	3.9	2.0
	Site of old Fort San Antonio	33 01 52	71 38 42				
	Quintero Point: Summit	32 46 00	71 32 56	9 35	3 25	4.1	2.1
	Pichidangui: SE. pt. of island	32 07 55	71 33 22	9 30	3 20	3.9	2.0
	Tablas Point: SW. extreme	31 51 45	71 34 51	9 26	3 16	4.2	2.1
	Chuapa River: S. entrance pt	31 39 30	71 35 20				
	Maitencillo Cove: N. head	31 17 05	71 39 21				
	Talinay Mount: Summit	30 50 45	71 39 00				
	Lengua de Vaca: Lighthouse	30 14 00	71 39 00				
	Port Tongoi: Obs. spot. W. of village	30 15 14	71 31 09	9 15	3 05	4.1	2.1
	Coquimbo: Tortuga Pt. light	29 56 15	71 21 00	8 58	2 48	4.9	2.5
	Smelting works, N. of town	29 56 24	71 21 53				
	N. islet	29 55 10	71 22 21				
	Pajaros Islets: Lighthouse	29 34 40	71 33 20				
	Choros Islands: SW. pt. of largest island	29 15 45	71 34 38				
	Chañaral Island: Lighthouse	29 00 50	71 36 40				
	Huasco: Light on mole	28 27 20	71 15 45	8 23	2 10	4.9	2.5
	Herradura de Carrizal: Landing place	28 05 45	71 12 48	8 50	2 38	4.9	2.5
	Port Carrizal: Middle Point	28 04 30	71 11 32				
	Matamoras Cove: Outer pt. S. side	27 54 10	71 09 38				
	Salado Bay: Summit of Cachos Pt	27 39 20	71 03 26				
	Copiapo: Landing place	27 20 00	70 58 45	8 21	2 08	5.0	2.5
	Caldera: Lighthouse	27 03 15	70 52 54	8 50	2 37	4.9	2.5
	Light on mole head	27 03 15	70 53 45				
	Cabeza de Vaca Point: Extreme	26 51 05	70 51 55				
	Flamenco: SE. corner of bay	26 34 30	70 44 25	9 00	2 47	5.0	2.5
	Chañaral Bay: Observation pt	26 20 00	70 37 25	9 05	2 52	4.9	2.5
	St. Felix I.: Peterborough Cathedral Rock	26 16 12	80 11 43				
	Pan de Azucar Island: Summit	26 09 15	70 43 57				

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF SOUTH AMERICA—Continued.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Chile.	Lavata: Cove near SW. pt	25 39 30	70 44 03	9 10	2 57	5.0	2.5
	San Pedro Point: Summit	25 31 00	70 41 18				
	Port Taltal: Lighthouse	25 25 20	70 34 10	9 20	3 07	4.9	2.5
	Grande Point: Outer summit	25 07 00	70 30 16	9 35	3 22	5.0	2.5
	Paposo Road: Huanillo Pt	25 05 25	70 29 50	9 30	3 17	4.9	2.5
	Reyes Head: Extreme pitch	24 34 30	70 36 29				
	Cobre Bay: Pt. W. of village	24 15 00	70 33 00				
	Jara Head: Summit	23 53 00	70 32 28				
	Antofagasta: Lighthouse	23 38 50	70 25 18	9 05	2 52	4.7	2.4
	Chimba Bay: E. pt. of large island	23 33 05	70 26 55				
	Moreno Mountain: Summit	23 28 30	70 34 56				
	Constitution Cove: Shingle pt. of island	23 26 42	70 37 11				
	Mexillones Mount: Summit	23 06 30	70 31 39	9 35	3 22	3.9	2.0
	Port Cobija: Landing place	22 34 00	70 17 42	9 44	3 31	4.0	2.0
	Tocopilla: Extremity Point	22 06 00	70 13 40	8 55	2 42	4.8	2.4
	San Francisco Head: W. pitch	21 55 50	70 11 17				
	Loa River: Mouth	21 28 00	70 02 45				
	Lobos Point: Outward pitch	21 05 30	70 12 12	9 00	2 47	4.9	2.5
	Pabellon de Pica: Summit	20 57 40	70 10 26				
	Patache Point: Extreme	20 51 05	70 14 40				
	Iquique: Lighthouse	20 12 30	70 11 20	8 35	2 22	5.0	2.5
	Mexillon Bay: Landing place	19 05 01	70 10 30				
	Pisagua: Pichalo Pt. extreme	19 36 30	70 15 21	8 32	2 20	5.0	2.5
	Gorda Point: W. low extreme	19 19 00	70 17 50				
	Lobos Point: Summit	18 45 40	70 21 50				
	Arica: Iron church	18 28 43	70 20 00	7 49	1 37	5.6	2.8
	Schama Mount: Highest summit	17 58 35	70 52 31				
Peru.	Coles Point: Extreme	17 42 00	71 22 31				
	Ilo: Mouth of rivulet	17 37 00	71 20 01	7 55	1 43	5.3	2.7
	Port Mollendo: Lighthouse	17 01 00	72 02 53				
	Islay: Customhouse	17 00 00	72 07 16	7 39	1 27	6.2	3.1
	Quilca: W. head of cove	16 42 20	72 27 16				
	Pescadores Point: SW. extreme	16 23 50	73 16 41				
	Atico: E. cove	16 13 30	73 41 31				
	Chala Point: Extreme	15 48 00	74 27 16				
	Lomas: Flagstaff on pt	15 33 15	74 51 01				
	San Juan Port: Needle Hammock	15 20 56	75 09 36	6 47	0 35	3.9	2.0
	Nasca Point: Summit	14 57 00	75 30 46				
	Mesa de Doña Maria: Central summit	14 41 00	75 49 56				
	Carreta Mount: Summit	14 09 50	76 16 36				
	San Gullan Island: N. summit	13 50 00	76 27 31				
	Paraca Bay: N. extreme of W. pt	13 48 00	76 18 31				
	Pisco: Lighthouse	13 45 00	76 10 00	6 16	0 04	3.8	1.9
	Chincha Islands: Boat slip, E. side N. id	13 38 20	76 24 15				
	Frayles Point: Extreme	13 01 00	76 31 06				
	Asia Rock: Summit	12 48 00	76 38 11				
	Chilca Point: SW. pitch	12 31 00	76 48 56				
	Morro Solar: Summit	12 11 30	77 02 31				
	San Lorenzo Island: Lighthouse	12 04 03	77 15 44				
	Callao: Palominos Rock Light	12 08 15	77 14 45	5 47	12 00	3.5	1.8
	Pescadores Islands: Summit of largest	11 47 10	77 16 11				
	Pelado Island: Summit	11 27 10	77 50 04				
	Supé: W. end of village	10 49 45	77 43 42				
	Huarmey: W. end of sandy beach	10 06 15	78 10 02	5 08	11 21	2.1	1.1
	Colina Redonda: Summit	9 38 35	78 21 33				
	Samanco Bay: Cross Pt	9 15 30	78 30 03				
	Chimbote: Village, N. part	9 04 40	78 35 57	4 50	11 03	2.0	1.0
	Chao Islet: Center	8 46 30	78 45 16				
	Guanape Islands: Summit of highest	8 34 50	78 56 53				
	Huanchaco Point: SW. extreme	8 05 40	79 06 46				
	Malabrigo Bay: Rocks	7 42 40	79 26 00	4 19	10 32	2.1	1.1
	Pacasmayo: Lighthouse	7 23 40	79 33 15				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF SOUTH AMERICA—Continued.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Peru.	Eten Head: Lighthouse	6 55 50	79 51 30	4 04	10 17	2.5	1.3
	Lambayeque: Beach opposite	6 46 00	79 57 55				
	Lobos de Afuera Island: Chichal de Afuera	6 57 04	80 43 00				
	Lobos de Tierra Island: Saenz Pt	6 29 12	80 52 12				
	Aguja Point: W. cliff summit	5 55 30	81 09 19				
	Paita Cathedral	5 05 02	81 07 17				
	Parinas Point: Extreme	4 40 50	81 17 01				
	Cape Blanco: Under middle of high cliff	4 16 40	81 12 01				
	Tumbez: Malpelo Pt	3 30 42	80 28 12				
Ecuador.	Guayaquil River: Light on Santa Clara I.	3 10 40	80 25 29	4 00	10 13	10.0	5.1
	Guayaquil, Concejo: S. pt. of city	2 12 24	79 52 19	7 00	1 00	11.0	5.6
	Puna: Mandinga Pt. light	2 44 30	79 53 45				
	Point Santa Elena: Veintemilla light	2 12 00	80 59 00	3 00	9 13	7.9	4.0
	Plata Isle: E. pt	1 16 55	81 03 55				
	Cape San Lorenzo: Marlinspike Rock	1 03 30	80 55 55				
	Manta Bay: Lighthouse	0 56 50	80 42 50	3 10	9 23	7.5	3.8
	Caraques Bay: Punta Playa	0 35 25	80 25 24				
	Cape Pasado: Extreme	0 21 30	80 30 37	3 15	9 28	9.9	5.0
		Lat. N.					
	Point Galera: N. extreme	0 50 10	80 05 40				
	Cape San Francisco: SW. extreme	0 40 00	80 07 55				
Colombia.	Esmeralda River: Lighthouse	1 03 30	79 42 00				
	Mangles Point: S. pt. of creek entrance	1 36 00	79 03 30				
	Tumaco: S. pt. of El Morro I	1 49 36	78 45 29	3 35	9 48	13.2	7.1
	Guascama Point: Extreme	2 37 10	78 24 24				
	Gorgona Island: Watering Bay	2 58 10	78 11 16				
	Buenaventura: Basin Pt	3 49 27	77 11 45	6 00	12 13	13.2	7.1
	Chirambiri Point: N. extreme	4 17 06	77 29 44				
	Cape Corrientes: SW. extreme	5 28 46	77 33 28	3 40	9 53	13.1	7.0
	Cupica Bay: Entrance to Cupica River	6 41 19	77 30 31	3 30	9 43	13.3	7.2
	Cape Marzo: SE. extreme	6 49 45	77 40 55				

ISLANDS IN THE ATLANTIC OCEAN.

Coast.	Place.	Lat.	Long.	H. W.	L. W.	Spg.	Neap.
	Færoe Islands, Strom Islet: Thorshaven Fort flagstaff	62 02 26	6 43 08				
	Halderoig Islet: Halderoig Church	62 18 20	7 00 36				
	Numken Rock	61 23 00	6 45 30				
	Rockall Islet: Summit, 70 feet	57 35 52	13 42 21				
Azores Islands.	Corvo Island: S. pt	39 40 07	31 08 00				
	Flores Island: Santa Cruz Fort	39 27 00	31 08 49				
	Fayal Channel: N. Magdalen Rock	38 32 09	28 34 00				
	Fayal Island, Horta: Castle of Santa Cruz	38 31 45	28 37 39	11 30	5 18	3.9	1.8
	Caldera: Summit 3,351 ft	38 34 30	28 44 00				
	Pico Island: Summit	38 25 00	28 28 12				
	St. George Island: Lighthouse	38 40 30	28 13 00				
	Graciosa Island: Santo Fort light	39 05 24	28 00 45				
	Terceira Island: Monte del Brazil, near Angra	38 38 20	27 13 45	0 20	6 32	4.4	2.0
	St. Michael Island: Customhouse, Ponta Delgada	37 44 16	25 40 40				
	Pt. Arnel light	37 49 20	25 08 21	0 15	6 27	5.7	2.6
	Santa Maria Island: Villa do Porto light	36 56 00	25 10 00				
	Formigas Islands: Highest rock	37 16 44	24 47 06				

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS IN THE ATLANTIC OCEAN—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Madeira Is.	Porto Santo Island: Lighthouse	33 03 15	16 16 20	0 40	6 52	6.6	3.0
	Desertas: Chao I., Sail Rock	32 35 45	16 33 30				
	Madeira Island: Funchal light	32 37 43	16 54 53	0 35	6 47	6.6	3.0
	Fora I. lighthouse	32 43 14	16 39 31				
	Pico Ruivo, summit, 6,056 ft	32 45 00	16 57 30				
	Pargo (W.) Pt	32 48 07	17 16 05				
	Salvage Islands: Lighthouse, Gran Salvage I	30 08 00	15 54 00				
Canary Islands.	Alegranza Island: Delgada Pt. light	29 23 50	13 29 31				
	Lanzarote Island: Port Naos light	28 57 24	13 33 07	0 50	7 00	8.5	3.9
	Pechinguera Pt. light	28 50 56	13 52 05				
	Lobos Island: Martino Pt. light	28 45 25	13 49 13				
	Fuerta Ventura Island: Jandia Pt. light	28 03 00	14 31 35				
	Gran Canaria: Isleta Pt. light	28 10 42	15 25 11	0 40	6 50	9.3	4.3
	Palmas light	28 07 06	15 24 56				
	Teneriffe Island: Anga Pt. light	28 35 25	16 08 11				
	Santa Cruz, Br. consulate	28 28 12	16 15 09	1 15	7 27	7.8	3.6
	Summit of peak, 12,180 ft	28 16 35	16 38 02				
	Gomera Island: Port Gomera	28 08 00	17 05 55				
	Ferro Island: Port Hierro	27 46 30	17 54 22				
	Palma Island: Light, NE. pt	28 50 06	17 47 01	0 20	6 30	8.6	4.0
Cape Verde Islands.	San Antonio Island: Bull Pt. light	17 06 50	24 59 15				
	Summit, 7,400 ft	17 04 00	25 17 00				
	St. Vincent Island: Porto Grande light	16 53 14	24 59 30	5 50	12 00	3.3	1.5
	St. Lucia Island: N. pt	16 49 00	24 47 08				
	Raza Island: E. pt	16 38 00	24 38 08				
	St. Nicholas Island: Lighthouse	16 34 00	24 16 00				
	Sal Island: N. pt. light	16 50 50	22 54 55				
	S. pt	16 34 00	22 55 42	7 30	1 20	4.4	2.0
	Boavista Island: NW. pt	16 13 20	22 55 44				
	NE. pt	16 11 00	22 42 00				
	Lighthouse	16 09 10	22 57 20				
	Mayo Island: English Road	15 07 30	23 12 42				
	St. Jago Island: Reta Pt. light	15 18 06	23 47 06				
	Porto Praya, S. light	14 53 40	23 31 45	5 50	12 00	4.8	2.2
	Fogo Island: N. S. da Luz, village	14 53 00	24 30 38				
	Brava Island: Lighthouse	14 50 30	24 40 00				
Bermuda Is.	Ireland Island: Dock yard clock tower	32 19 22	64 49 35	7 04	0 52	4.0	2.6
	Bastion C	32 19 37	64 49 15				
	Hamilton Island: Gibbs Hill light	32 15 05	64 49 40				
	St. Davids Island: Lighthouse	32 21 40	64 38 40				
	St. Paul Rocks: Summit, 64 ft	0 55 30	29 22 28				
		Lat. S.					
	Rocas Reef: NW. sandy islet	3 51 30	33 49 29	5 05	11 18	10.0	4.6
	Fernando Noronha: The Pyramid	3 50 30	32 25 29	5 00	11 13	6.0	2.7
	Ascension Island: Fort Thornton	7 55 20	14 24 35	5 20	11 30	2.0	0.9
	St. Helena Island: Obs. Ladder Hill	15 55 00	5 43 03	3 00	9 10	2.8	1.3
	Martin Vaz Rocks: Largest islet	20 27 42	28 46 57	3 35	9 48	3.5	1.6
	Trinidad Island: SE. pt	20 30 32	29 14 56	3 40	9 53	4.0	1.8
	Inaccessible Island: Center	37 19 00	12 23 00				
	Tristan da Cunha Islands: NW. pt	37 02 48	11 18 39	12 50	5 40	5.2	2.4
	Gough Island: Penguin Islet	40 19 11	9 56 11				

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MARITIME POSITIONS AND TIDAL DATA.

ISLANDS IN THE ATLANTIC OCEAN—Continued.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Falkland Islands.	Port Egmont: Observation spot	51 21 26	60 04 52	7 20	1 08	10.7	5.6
	Mare Harbor: Observation spot	51 04 11	58 30 56				
	Port Louis: Flagstaff, govt. house	51 32 20	58 08 04	5 31	11 27	4.3	2.2
	Port Stanley: Governor's house	51 41 10	57 51 30				
	Cape Pembroke: Lighthouse	51 40 40	57 41 48				
	South Georgia Island: N. cape	54 04 45	38 15 00				
	Shag Rocks: Center	53 48 00	43 25 00				
	Sandwich Islands: S. Thulé	59 34 00	27 45 00				
	Traverse I. volcano	55 57 00	26 33 00				
	New S. Orkney Is.: E. pt. Laurie I	60 54 00	44 25 00				
	E. summit Coronation I., 5,397 ft	60 46 00	45 53 00				
	New S. Shetland Islands, Deception Island: Port Foster	62 55 36	60 35 00				
			Long. E.				
	Bouvets Island (Circumcision): Center	54 16 00	6 14 00				

ATLANTIC COAST OF EUROPE.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
Great Britain.	Greenwich: Observatory	51 28 38	0 00 00	1 10	7 46	18.8	12.6
	Oxford: University Observatory	51 45 34	1 15 06				
			Long. E.				
	Cambridge: Observatory	52 12 52	0 05 41				
	North Foreland: Lighthouse	51 22 28	1 26 48	11 24	5 53	16.8	8.4
	South Foreland: Lighthouse	51 08 23	1 22 22	11 09	5 43	19.8	10.0
	Dungeness: Lighthouse	50 54 47	0 58 18	10 35	4 23	21.5	11.0
	Beachy Head: Lighthouse	50 44 15	0 13 00	11 10	4 58	19.8	10.1
			Long. W.				
	Southsea Castle: Lighthouse	50 46 35	1 05 15				
	Portsmouth: Observatory	50 48 03	1 05 58	11 31	4 19	13.2	6.7
	Southampton: Royal Pier light	50 53 45	1 24 00	0 35	6 48	12.8	6.5
	Hurst Castle: W. light	50 42 07	1 33 04	11 05	4 53	12.2	6.2
	Needles Rocks: Old lighthouse	50 39 42	1 35 25				
	St. Catharine: New lighthouse	50 34 30	1 17 47				
	Portland: Notch Bill light	50 31 10	2 27 30	6 29	0 09	6.7	1.0
	Start Point: Lighthouse	50 13 18	3 38 28	5 25	11 38	14.9	6.8
	Plymouth: Breakwater light	50 20 02	4 09 27	5 20	11 33	15.3	7.0
	Eddystone: Lighthouse	50 10 49	4 15 53				
	Falmouth: St. Anthony Pt. light	50 08 30	5 01 00				
	Lizard Point: W. lighthouse	49 57 40	5 12 06	4 45	10 58	14.2	6.5
	Porthcurnow: SE. cor. telegraph co.'s sta.	50 02 44	5 39 18				
	Lands End: Longships lighthouse	50 04 10	5 44 45				
	Scilly Islands: St. Agnes lighthouse	49 53 33	6 20 38	4 15	10 28	15.9	7.3
	Trevose Head: Lighthouse	50 33 00	5 01 55				
	Bideford: High lighthouse	51 04 00	4 12 30	5 45	11 58	22.7	11.4
	Lundy Island: Lighthouse, N. pt	51 12 05	4 40 35	5 00	11 13	26.9	13.5
	Bristol: Cathedral	51 27 24	2 35 55	7 00	0 48	31.3	15.7
	Cardiff: Lighthouse, W. pier	51 27 48	3 09 42	6 45	0 33	36.2	18.1
	Swansea: Lighthouse, W. pier	51 36 50	3 56 00	5 45	11 58	27.1	13.6
	Caldy Island: Lighthouse	51 37 52	4 40 59	5 40	11 53	25.3	12.7
	St. Anns: Upper lighthouse	51 41 00	5 10 30	5 41	11 54	24.0	12.0
	Smalls Rocks: Lighthouse	51 43 15	5 40 15	5 40	11 53	20.9	10.5
	Aberystwith: Lighthouse	52 24 20	4 05 40	7 25	1 13	14.2	7.1
	Bardsey Island: Lighthouse	52 45 00	4 47 50	7 24	1 12	14.9	7.5
	South Stack: Lighthouse on rocks	53 18 30	4 42 00				
	Holyhead: Lighthouse on old pier	53 18 54	4 37 01	10 00	3 48	15.8	7.9

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Great Britain.	Skerries Rocks: Lighthouse, highest I	53 25 15	4 36 20				
	Bidstone: Lighthouse on hill	53 24 02	3 10 42				
	Liverpool: Rock light	53 26 38	3 02 27				
	Bidston Observatory	53 24 05	3 04 20	11 08	5 27	27.6	14.0
	Morecambe Bay: Fleetwood high light	53 55 03	3 00 20	11 00	4 48	27.4	13.9
	Calf of Man: Upper lighthouse	54 03 14	4 49 37				
	Isle of Man: Ayre Pt. lighthouse	54 24 56	4 22 01	10 55	4 43	19.7	10.0
	St. Bees: Lighthouse	54 30 50	3 37 50				
	White Haven: W. pierhead light	54 33 00	3 36 00	11 00	4 48	25.9	13.1
	Mull of Galloway: Lighthouse	54 38 10	4 51 20	11 05	4 53	14.8	8.9
	Ayr, Firth of Clyde: Lighthouse, N. side harbor	55 28 10	4 38 10	11 40	5 28	8.7	5.2
	Troon: Lighthouse, inner pier	55 32 55	4 41 00				
	Ardrossan: S. breakwater light	55 38 27	4 49 28	11 35	5 23	8.8	5.3
	Pladda Island: Lighthouse	55 26 00	5 07 09				
	Glasgow: Observatory	55 52 43	4 17 38	0 55	7 08	11.2	6.7
	Cantyre: Lighthouse	55 18 39	5 48 00	10 20	4 08	4.0	2.4
	Rhynns of Islay: Lighthouse	55 40 20	6 30 46				
	Oban: Lighthouse on N. pier	56 24 50	5 28 20	5 10	11 22	12.8	7.7
	Skerryvore Rocks: Lighthouse	56 19 22	7 06 32				
	Barra Head: Lighthouse	56 47 08	7 39 09	5 35	11 47	11.1	4.8
	Glas Island: Lighthouse, Scalpay I	57 51 25	6 38 28				
	Stornoway: Arnish Pt. light	58 11 28	6 22 10	6 35	0 22	13.4	5.7
	Butt of Lewis: Lighthouse	58 30 40	6 16 01				
	Cape Wrath: Lighthouse	58 37 30	4 59 41				
	Dunnet Head: Lighthouse	58 40 16	3 22 25				
	Kirkwall (Orkneys): New pierhead light	58 59 15	2 57 33	9 57	3 44	9.8	4.2
	Startpoint (Orkneys): Lighthouse	59 16 45	2 22 25				
	North Ronaldsay: Lighthouse	59 23 24	2 22 45				
	Fair Isle Skroo: Lighthouse	59 33 00	1 36 30	10 50	4 37	5.0	2.2
	Sumburgh Head: Lighthouse	59 51 15	1 16 20	9 35	3 22	5.2	2.2
	Blackness (Shetland Is.): Lighthouse pier	60 08 02	1 16 02				
	Lerwick (Shetland Is.): Fort	60 09 22	1 08 41	10 20	4 17	6.0	2.6
	Hillswickness (Shetland Is.): S. extreme	60 27 20	1 29 50				
	Balta I. (Shetland Is.): Cairn on E. side	60 44 25	0 47 30	9 30	3 17	6.4	2.7
	Pentland Skerries: Upper lighthouse	58 41 22	2 55 25	10 00	3 47	9.8	4.2
	Tarbertness: Lighthouse	57 51 54	3 46 30				
	Buchanness: Lighthouse	57 28 15	1 46 22	0 24	6 36	11.2	6.1
	Aberdeen (Girdleness): Lighthouse	57 08 33	2 04 06	0 50	7 02	11.7	6.4
	Buddonness: Upper lighthouse	56 28 07	2 44 53	1 56	8 08	15.5	8.5
	Bell Rock: Lighthouse	56 26 03	2 23 06				
	May Island: Lighthouse	56 11 00	2 33 22				
	Inch Keith Rock: Lighthouse	56 02 09	3 08 05				
	Edinburgh: City observatory	55 57 23	3 10 47	1 58	8 11	16.5	8.9
	Berwick: Lighthouse	55 46 00	1 59 00	2 08	8 28	16.0	7.5
	Farn Island: NW. lighthouse	55 37 00	1 39 00				
	Coquet Island: Lighthouse	55 20 06	1 32 00				
	Tynemouth: Souter Point lighthouse	54 58 10	1 21 30				
	North Shields: Lighthouse	55 00 30	1 26 00	3 11	9 31	14.8	7.4
	Sunderland: N. pier light	54 55 07	1 21 30	3 12	9 32	14.5	7.3
	Hartlepool: Lighthouse	54 41 51	1 10 19	3 21	9 43	14.2	7.0
	Flamborough: New lighthouse	54 07 00	0 05 00	4 20	10 36	15.8	8.8
	Humber River: Killingholme middle light	53 39 00	0 12 00				
			Long. E.				
	Spurn Head: Upper lighthouse	53 34 45	0 07 10	5 16	11 29	18.5	10.2
	Lowestoft: Lighthouse	52 29 14	1 45 24	9 47	3 35	6.2	3.6
	Orfordness: N. lighthouse	52 05 00	1 34 30	11 05	4 53	7.8	4.5
	Harwich: Landguard Pt. light	51 56 05	1 19 10	11 56	5 44	11.2	6.6

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Great Britain.	Cape Clear: Old lighthouse	51 26 02	9 29 03	3 50	10 03	8.8	4.4
	Fastnet Rock: Lighthouse	51 23 18	9 36 25				
	Mount Gabriel: Ordnance survey station	51 33 24	9 32 44				
	Castlehaven: Lighthouse	51 31 00	9 10 20	4 10	10 23	10.6	5.3
	Mizen Hill: Ordnance survey station	51 27 41	9 48 19				
	Bantry Bay: Roancarrig light	51 39 10	9 44 49				
	Bull Rock: Lighthouse	51 35 30	10 18 03				
	Skelligs Rocks: Lighthouse	51 46 14	10 32 45				
	Valentia: Lighthouse	51 56 00	10 19 16	3 30	9 43	10.8	4.6
	Port Magee	51 53 08	10 23 17				
	Dingle Bay: Light at entrance	52 07 15	10 15 30	3 40	9 53	10.7	4.6
	Blasket Islands: Westernmost rock	52 04 30	10 40 00				
	Smerwick: Signal tower	52 13 46	10 21 40	3 40	9 53	10.7	4.6
	Tralee Bay: Lighthouse	52 16 14	9 52 53	3 50	10 03	12.3	5.3
	Beeves Rocks: Lighthouse	52 39 00	9 01 18				
	Limerick: Cathedral	52 40 04	8 37 23	6 00	0 13	18.7	8.0
	Shannon River: Loop Head light	52 33 38	9 55 54				
	Eeragh Island: Lighthouse	53 08 55	9 51 30				
	Arran Island: Lighthouse	53 07 38	9 42 06	4 15	10 28	13.4	5.7
	Galway: Mutton I. light	53 15 13	9 03 10	4 19	10 19	15.1	6.4
	Golam Head: Tower	53 13 46	9 46 03				
	Slyne Head: N. lighthouse	53 23 58	10 14 01	4 16	10 29	13.2	5.7
	Clifden Bay: Gortrumnagh Hill	53 29 47	10 03 54				
	Tully Mountain: Ordnance survey station	53 35 00	10 00 15				
	Inishboffin: Lyon Head light	53 36 40	10 09 40	4 20	10 33	12.1	5.2
	Inishturk Island: Tower	53 42 27	10 06 41				
	Clew Bay: Inishgort light	53 49 34	9 40 12				
	Newport: Church	53 53 06	9 32 56				
	Clare Island: Lighthouse	53 49 30	9 59 00				
	Blacksod Point: Lighthouse	54 05 45	10 03 34				
	Eagle Island: W. lighthouse	54 17 00	10 05 31				
	Broadhaven: Guba Cashel light	54 16 00	9 53 00	4 50	11 03	10.4	4.5
	Dounpatrick Head: Ordnance survey station	54 19 36	9 20 41				
	Anghris Head: Ordnance survey station	54 16 33	8 46 02				
	Knocknarea: Tumulus	54 15 30	8 34 25				
	Sligo Bay: Black Rock light	54 18 00	8 37 00	5 10	11 23	11.4	5.3
	Knocklane: Ordnance survey station	54 20 50	8 40 14				
	Killybegs (Donegal Bay): St. Johns Pt. light	54 34 08	8 27 33	5 03	11 16	11.2	4.8
	Rathlin O'Birne Islet: Lighthouse	54 39 47	8 49 52				
	Aran Island: Rinrawros light	55 00 52	8 33 48				
	Bloody Foreland: Ordnance survey station	55 08 13	8 15 38				
	Tory Island: Lighthouse	55 16 26	8 15 00				
	Horn Head: Ordnance survey station	55 12 31	7 57 15				
	Melmore Head: Tower	55 15 14	7 47 12	5 28	11 41	11.6	5.3
	Fanad Point: Lighthouse	55 16 33	7 37 53				
	Glashedy Island: Ordnance survey station	55 19 07	7 23 51				
	Malin Head: Tower	55 22 50	7 22 22				
	Inishtrahull: Lighthouse	55 25 55	7 13 37				
	Inishowen Head: E. lighthouse	55 13 38	6 55 38				
	Moville: New Pier	55 10 20	7 02 20	6 55	0 43	7.5	3.4
	Londonderry: Cathedral	54 59 40	7 19 25	7 48	1 35	8.0	3.6
	Scalp Mountain: Ordnance survey station	55 05 23	7 21 51				
	Benbane Head: Summit	55 15 03	6 28 45				
	Rathlin Island: Altacarry lighthouse	55 18 05	6 10 45				
	Maiden Rocks: W. lighthouse	54 55 47	5 44 18	10 30	4 18	6.7	4.5
	Lough Larne: Farres Pt. lighthouse	54 51 07	5 47 21				
	Belfast Bay: Light, east side	54 40 20	5 49 30	10 42	4 06	9.3	6.3
	Mew Islands: Lighthouse	54 41 50	5 31 30				
	Donaghadee: Lighthouse	54 38 45	5 32 01	11 00	4 48	11.1	7.4
	South Rock: Light vessel	54 24 04	5 22 20				

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Great Britain.	Dundrum Bay: St. John Pt. light	54 13 30	5 39 30				
	Carlingford Lough: Haulbowline Rk. lt.	54 01 10	6 04 45	10 45	4 33	15. 8	9. 2
	Drogheda: Lighthouse	53 43 00	6 15 00	10 45	4 33	11. 6	6. 8
	Rockabill: Lighthouse	53 35 47	6 00 20				
	Howth Peninsula: Bailey light	53 21 40	6 03 06	10 55	4 43	12. 7	7. 5
	Dublin: Observatory	53 23 13	6 20 17				
	N. wall light	53 20 47	6 13 33				
	Poolbeg: Lighthouse	53 20 30	6 09 00	11 00	4 48	13. 0	7. 6
	Kingstown: E. pier light	53 18 10	6 07 30	10 52	4 27	10. 9	6. 4
	Killiney Hill: Mapas obelisk	53 15 52	6 06 37				
	Bray Head: Ordnance survey station	53 10 39	6 04 55	10 30	4 18	11. 8	6. 9
	Wicklow: Upper light	52 57 54	6 00 08	10 10	3 58	8. 7	5. 1
	Tara Hill: Summit	52 41 55	6 13 01				
	Black Stairs Mountain: Ordnance survey station	52 32 55	6 48 17				
	Tory Hill: Ordnance survey station	52 20 53	7 07 31				
	Wexford: College	52 20 04	6 28 15	7 05	0 53	4. 9	2. 9
	Forth Mount: Ordnance survey station	52 18 57	6 33 41				
	Tuskar Rock: Lighthouse	52 12 09	6 12 35	5 30	11 43	8. 8	5. 1
	Great Saltee: S. end	52 06 41	6 37 15				
	Waterford: Hoop Pt. light	52 07 25	6 55 53	5 05	11 18	12. 3	6. 2
	Waterford: Cathedral	52 15 33	7 06 24				
	Great Newton Head: Metal Man Tower	52 08 13	7 10 15				
	Dungarvan: Ballinacourty light	52 04 27	7 33 05	5 00	11 13	12. 4	6. 2
	Knockmealdown Mount: Ordnance survey station	52 13 39	7 54 54				
	Helvick Head: Ordnance survey station	52 03 00	7 32 39				
	Mine Head: Lighthouse	51 59 33	7 35 08				
	Youghal: Lighthouse	51 56 34	7 50 34	5 02	11 15	12. 6	6. 3
	Capel Island: Tower	51 52 54	7 51 10				
	Ballycottin: Lighthouse	51 49 30	7 59 00	4 40	10 53	11. 8	5. 9
	Cork Harbor: Haulbowline Coal Wharf	51 50 33	8 18 20				
	Queenstown: Roches Pt. light	51 47 33	8 15 14	4 33	10 59	11. 6	5. 8
	Kinsale: Lighthouse, S. pt	51 36 11	8 31 58	4 30	10 43	11. 4	5. 7
	Seven Heads: Tower	51 34 14	8 42 51	4 20	10 33	10. 7	5. 3
	Galley Head: Light on summit	51 31 50	8 57 10				
	Stag Rocks: Largest	51 28 05	9 13 27				
	Alderney Harbor: Old pier light	49 43 00	2 12 00	6 21	0 16	17. 2	7. 6
	St. Heliers: Light on Victoria Pier	49 10 29	2 06 44	6 09	0 00	31. 2	13. 6
			Long. E.				
Norway.	Vardo: Fortress	70 22 00	31 07 30	5 40	11 57	9. 0	5. 1
	Vadso: Lighthouse	70 04 00	29 45 00				
	North Cape: Extreme	71 11 00	25 40 00				
	Fruholm: Lighthouse	71 06 00	23 59 00				
	Hammerfest: Lighthouse	70 40 15	23 40 00	2 20	8 40	8. 3	4. 7
	Tromso: Observatory	69 39 12	18 57 00	1 35	7 48	7. 8	4. 4
	Hekkingen: Lighthouse	69 36 05	17 50 15				
	Andenes: Lighthouse	69 19 30	16 08 00	0 42	6 55	7. 0	4. 0
	Lodingen (Hjertholm): Lighthouse	68 24 40	16 02 30				
	Lofoten Island: Skraaven I. light	68 09 20	14 40 40				
	Glopen light	67 53 15	13 04 30				
	Gryto: Lighthouse	67 23 15	13 52 30				
	Stot: Lighthouse	66 56 35	13 28 50				
	Trænen: Soe Islet light	66 25 50	11 59 50	11 35	5 23	6. 9	3. 3
	Bronnosund: Lighthouse	65 28 40	12 13 30				
	Villa: Lighthouse	64 32 55	10 42 10				
	Halten Island: Lighthouse	64 10 25	9 24 50				
	Koppem	63 48 25	9 44 45				
	Agdenes: Lighthouse	63 38 45	9 45 20				
	Trondheim: Mumkholmen flagstaff	63 27 04	10 23 30	11 18	5 04	8. 4	4. 1
	Grip: Church	63 13 11	7 36 05				
	Christiansund: Storvaden	63 07 01	7 43 35	11 00	4 48	5. 0	2. 9
	Freikallen	63 03 04	7 46 04				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Norway.	Hestskjaer: Lighthouse	63 05 00	7 29 55				
	Stemshesten	62 58 49	7 12 32				
	Ærstenen: Lighthouse	62 48 20	6 36 10				
	Svinoen Islet	62 19 38	5 16 25				
	Hjœrringa Mountain: Summit	62 11 12	5 07 59				
	Hornelen Mountain: Summit	61 51 21	5 15 11				
	Batalden Island: Store	61 38 40	4 47 38				
	Kinnsund: Lighthouse	61 33 35	4 46 45				
	Alden	61 19 16	4 47 14				
	Helliso: Lighthouse	60 45 05	4 42 55				
	Bergen: Naval School Obsy	60 23 54	5 18 11	10 15	3 55	4.1	2.1
	Lorstakken Mountain: Summit	60 21 39	5 19 35				
	Marstenen Islet: Lighthouse	60 07 50	5 01 00				
	Furen Islet	59 57 44	5 03 30				
	Ulsire: Lighthouse	59 18 20	4 52 35				
	Hvidingso: Lighthouse	59 03 10	5 24 20				
	Port Stavanger: Lighthouse	58 58 30	5 45 20	9 43	3 40	1.9	0.8
	Obristadbrœkke: Lighthouse	58 39 25	5 33 35				
	Synesvarde Mountain: Summit	58 36 56	5 49 08				
	Kompas Mountain: Summit	58 25 51	5 58 49				
	Lister: Lighthouse	58 06 25	6 34 20				
	Lindesnes: Lighthouse	57 58 55	7 03 10				
	Ryvingen Island: Lighthouse	57 58 00	7 29 50				
	Christianssand: Odderoen light	58 07 50	8 00 30	4 16	10 15	1.1	0.5
	Okso: Lighthouse	58 04 15	8 03 30				
	Hamberg: Mill	58 15 02	8 31 36				
	Arendal Inlet: Inner Torungerne light	58 24 40	8 47 55	4 17	10 10	1.0	0.7
	Jomfruland: Lighthouse	58 51 50	9 36 15				
	Langotangen: Lighthouse	58 59 25	9 45 50				
	Langesund: Church	59 00 01	9 45 14				
	Frederiksværn: Lookout tower	58 59 34	10 03 28	4 34	10 00	1.3	1.0
	Svenor: Lighthouse	58 58 05	10 09 26				
	Fœrder Islet: Lighthouse	59 01 35	10 31 55				
	Fulehuk: Lighthouse	59 10 30	10 36 25				
	Basto: Lighthouse	59 23 10	10 32 45				
	Horten: Church	59 25 34	10 29 52				
	Holmestrand: Church	59 29 23	10 19 15				
	Drobak: Church	59 39 52	10 38 08				
	Oscarsberg: Fort flagstaff	59 40 21	10 36 55				
	Christiania: Observatory	59 54 44	10 43 23	5 22	10 37	1.2	0.9
	Stromtangen (Torgauten): Lighthouse	59 09 00	10 50 15				
	Fredriksten: Fort clock tower	59 07 08	11 24 09				
	Torbjornskjær: Lighthouse	58 59 45	10 47 20				
	Koster: Lighthouse	58 54 05	11 00 45				
Sweden.	Stromstad: Steeple	58 56 24	11 10 28				
	Nord Koster Islands: Lighthouse	58 54 12	11 00 36				
	Wadero Island: Lighthouse	58 32 45	11 02 16				
	Hollo Island: Lighthouse	58 20 12	11 13 24				
	Paternoster Rocks: Lighthouse	57 53 49	11 28 04				
	Gottenburg: Signal station	57 40 58	11 53 54				
	Nidingen Islet: Lighthouse	57 18 15	11 54 16				
	Warberg: Castle tower	57 06 26	12 14 32				
	Falkenberg: Church	56 54 08	12 29 48				
	Halmstad: Palace	56 40 21	12 51 38				
	Engelholm: Church	56 14 40	12 51 47				
	Kullen Point: Lighthouse	56 18 06	12 27 11				
	Helsingborg: Lighthouse	56 02 37	12 41 30				
	Landskrona: Lighthouse	55 52 00	12 49 48				
	Lund: Royal Observatory	55 41 52	13 11 15				
	Malmo: Lighthouse	55 36 47	12 59 49				
	Falsterbo: Lighthouse	55 23 00	12 49 02				

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Sweden.	Trelleborg: Lighthouse	55 22 00	13 09 20				
	Ystad: Lighthouse	55 25 42	13 49 38				
	Sandhammaren: Lighthouse	55 22 58	14 11 10				
	Hano Island: Lighthouse	56 00 54	14 50 57				
	Karlshamn: Lighthouse	56 10 04	14 52 02				
	Karlskrona: Stumholm Tower	56 09 45	15 36 05				
	Oland Island: Light on S. pt	56 11 50	16 24 04				
	Gottland Island: Hoburg light, S. pt	56 55 18	18 11 06				
	Ostergarns light	57 26 29	18 59 27				
	Faro Island: Holmadden light	57 57 24	19 22 36				
	Sparo Vestervik: Granso light	57 45 38	16 40 36				
	Haradsskar Islet: Lighthouse	58 08 52	16 59 22				
	Norrkopings Inlopp: Lighthouse	58 17 55	16 11 28				
	Landsort: Lighthouse	58 44 26	17 52 09				
	Stockholm: Observatory	59 20 33	18 03 30				
	Upsala: Observatory	59 51 29	17 37 32				
	Norrtelge: Inn	59 45 24	18 41 34				
	Soderarm: Lighthouse	59 45 15	19 24 34				
	Svartklubben: Lighthouse	60 10 35	18 49 49				
	Osthammar: Church	60 15 19	18 22 36				
	Oregrund: Clock tower	60 20 26	18 26 33				
	Djursten: Lighthouse	60 22 15	18 24 21				
	Forsmark: Church	60 22 26	18 09 49				
	Orskar Rock: Lighthouse	60 31 41	18 22 38				
	Gefle: Church	60 40 29	17 08 29				
	Eggegrund Islet: Lighthouse	60 43 48	17 33 50				
	Hamrange: Church	60 55 57	17 02 57				
	Soderhamm: Courthouse	61 18 22	17 04 18				
	Enanger: Church	61 32 54	17 01 51				
	Hudiksvalls: Courthouse	61 43 57	17 07 37				
	Gnarp: Church	62 02 51	17 16 22				
	Sundsvall: Church	62 23 30	17 19 05				
	Lungo: Lighthouse	62 38 35	18 05 05				
	Skags Head: Lighthouse	63 11 55	19 02 50				
	Holmogadd: Lighthouse	63 35 34	20 45 35				
	Umea: Bredekar Light	63 39 33	20 18 35				
	Bjuroklubb: Lighthouse	64 28 50	21 34 45				
	Pitea	65 19 10	21 30 00				
	Rodkallen: Lighthouse	65 18 53	22 21 55				
	Maloren: Lighthouse	65 31 30	23 34 00				
Russia.	Tornea: Lighthouse	65 48 30	24 12 00				
	Uleaborg: Karlo I. light	65 02 20	24 34 00				
	Ulko Kalla Rock: Lighthouse	64 20 05	23 27 00				
	Norrsher Islet: Kvarken light	63 14 08	20 37 40				
	Kaske: Shelgrund I. light	62 20 06	21 11 24				
	Bierneborg: Sebsher light	61 28 29	21 22 34				
	Nuistad: Ensher light	60 43 10	21 01 00				
	Abo: Observatory	60 26 57	22 17 03				
	Aland Island: Shelsher light	60 24 45	19 34 00				
	Ekkere light	60 13 20	19 31 20				
	Logsher light	59 50 50	19 54 05				
	Bogsher: Beacon	59 31 11	20 25 50				
	Ute Islet: Lighthouse	59 46 30	21 22 00				
	Gange: Gange I. light	59 46 00	22 58 08				
	Rensher: Lighthouse	59 56 10	24 24 43				
	Helsingfors: Observatory	60 09 43	24 57 17				
	Soder Skars: Lighthouse	60 06 40	25 25 51				
	Kalboden Island: Light vessel	59 58 45	25 37 30				
	Rodsher Island: Lighthouse	59 58 08	26 41 05				
	Hogland Island: Lower light	60 00 40	27 01 40				
	Upper light	60 06 22	26 58 44				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Russia.	Sommer Island: Lighthouse	60 12 31	27 33 46				
	Vieborg Bay: Nelva I. light	60 14 43	27 58 36				
	Stirsudden: Lighthouse	60 11 05	29 03 01				
	Kronstadt: Light on Frederikstadt bastion	59 58 14	29 47 12				
	Cathedral	59 59 44	29 46 07				
	St. Petersburg: Observatory	59 56 30	30 19 22				
	Pulkowa: Observatory	59 46 19	30 19 40				
	Peterhof: Pier-head light	59 53 26	29 54 54				
	Oranienbaum: Lighthouse	59 55 40	29 46 38				
	Seskar Islet: Lighthouse	60 02 08	28 23 01				
	Narva: Light S. pt. of entrance	59 28 04	28 03 31				
	Stensher Rock: Lighthouse	59 49 10	26 23 00				
	Ekholm Islet: Lighthouse	59 41 06	25 48 58				
	Koksher: Lighthouse	59 42 00	25 02 37				
	Revel: Light N. end of W. mole	59 27 05	24 46 10				
	Cathedral	59 26 28	24 44 45				
	Nargen Island: Lighthouse	59 36 22	24 31 57				
	Surop: W. light	59 27 55	24 24 05				
	Baltic Port: Lighthouse	59 21 30	24 04 30				
	Odenskholm Island: Lighthouse	59 18 06	23 23 15				
	Takhkona Point: Lighthouse	59 05 25	22 36 15				
	Dago Island: Dagerort light	58 55 02	22 11 36				
	Filzand Island: Lighthouse	58 23 02	21 49 56				
	Svalferort Tzerel: Lighthouse	57 54 37	22 04 15				
	Kuino: Lighthouse	58 05 50	23 59 34				
	Pernau: Light at S. entrance	58 23 10	24 49 25				
	Riga: Ust Dyinski light	57 03 38	24 01 27				
	Cathedral of St. Peter	56 57 01	24 06 38				
	Runo Island: Lighthouse	57 48 02	23 15 00				
	Domesnes: Lighthouse	57 48 10	22 39 15				
	Windau: Light on S. jetty	57 24 00	21 34 00				
	Libau: Light at entrance of port	56 31 01	20 59 40				
Germany.	Memel: Lighthouse	55 43 45	21 06 06				
	Heiligen Creutz: Church tower	54 53 47	20 01 25				
	Brusterort: Lighthouse	54 57 40	19 59 06				
	Pillau: Lighthouse	54 38 25	19 53 55				
	Fischausen: City Hall tower	54 43 49	20 00 39				
	Konigsberg: Observatory	54 42 50	20 29 46				
	Tolkemit: Church tower	54 19 19	19 31 58				
	Elbing: Church tower	54 09 44	19 23 58				
	Tiegenort: Church tower	54 16 30	19 08 37				
	Dantzig: Observatory	54 21 18	18 39 54				
	Neufahrwasser light	54 24 28	18 39 59				
	Weichselmunde: Fortress tower	54 23 51	18 41 03				
	Putziger Heisternest: Church tower	54 12 16	18 40 35				
	Oxhoft: Lighthouse	54 33 09	18 33 46				
	Hela: Lighthouse	54 36 06	18 49 04				
	Rixhoft: Lighthouse	54 49 55	18 20 29				
	Leba: Church tower	54 45 29	17 33 38				
	Stopelmunde: Church	54 35 16	16 51 35				
	Jershoft: Lighthouse	54 32 29	16 32 50				
	Rugenwalde: St. Mary's Church	54 25 27	16 24 52				
	Coslin: St. Mary's Church	54 11 28	16 11 05				
	Funkenhagen: Lighthouse	54 14 40	15 52 39				
	Colberg: St. Mary's Church	51 10 40	15 34 44				
	Gross-Horst: Lighthouse	54 05 47	15 04 06				
	Cammin: Cathedral tower	53 58 29	14 46 36				
	Wollin: Church tower	53 50 41	14 37 12				
	Stettin: N. Castle tower	53 25 41	14 33 52				
	Swinemunde: Lighthouse	53 55 03	14 17 19				

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Germany.	Streckelsberg: Survey station near beacon	54 03 08	14 01 17				
	Usedom: Church tower	53 52 17	13 55 26				
	Lassau: Church tower	53 56 59	13 51 13				
	Wolgast: Church tower	54 03 18	13 46 51				
	Griefswald: St. Nicholas Church	54 05 49	13 22 53				
	Griefswalder Oie: Lighthouse	54 15 02	13 55 42				
	Granitz: Castle tower	54 22 56	13 37 54				
	Bergen: Church tower	54 25 08	13 26 11				
	Arkona: Lighthouse	54 40 53	13 26 12				
	Stralsund: St. Mary's Church	54 18 42	13 05 30				
	Darsserort: Lighthouse	54 28 28	12 30 23				
	Wustrow: Church	54 20 47	12 24 02				
	Ribnitz: Church tower	54 14 42	12 26 04				
	Warnemunde: Church	54 10 42	12 05 19				
	Rostock: St. Jacob's Church	54 05 27	12 08 10				
	Diedrichshagen: Survey station	54 06 32	11 46 04				
	Basdorf: Survey station	54 08 00	11 41 54				
	Wismar: St. Nicholas Church	53 53 50	11 28 09				
	Hohenschonberg: Survey station	53 58 54	11 05 54				
	Travemunde: Lighthouse	53 57 44	10 52 59				
	Burg: Church tower	54 26 16	11 11 59				
	Marienleuchte: Lighthouse	54 29 43	11 14 29				
	Petersdorf: Church tower	54 28 54	11 04 18				
	Hessenstein: Flagstaff of lookout tower	54 19 47	10 32 59				
	Schonberg: Church	54 23 52	10 22 24				
	Bulk: Lighthouse	54 27 25	10 12 04				
	Kiel: Observatory	54 20 28	10 08 53				
	Eckemforde: Church	54 28 25	9 50 23				
	Schleswig: Cathedral	54 30 55	9 34 23				
	Kappeln: Church	54 39 48	9 56 13				
	Flensberg: Church	54 47 05	9 26 20				
	Duppel: Survey station	54 54 28	9 45 35				
	Schleimunde: Lighthouse	54 40 23	10 02 23				
	Augustenburg: Church	54 56 48	9 52 20				
	Hugeberg: Survey station	54 58 05	9 58 41				
	Apenrade: Church	55 02 46	9 25 18				
	Skoorgaarde: Survey station	55 03 52	9 23 35				
	Ballum: Church	55 05 31	8 39 41				
	List: E. lighthouse	55 03 04	8 26 50	0 20	6 33	5.2	3.0
	Keitum: Church	54 54 13	8 22 03				
	Fohr: St. Nicholas Church	54 41 51	8 33 13	1 35	7 47	7.8	4.5
	Galgenberg: Survey station	54 41 21	8 33 58				
	Husum: Church	54 28 43	9 03 21	2 10	8 23	10.8	6.2
	Tonning: Church	54 19 08	8 56 38	1 45	7 57	11.0	6.4
	Busum: Church	54 07 52	8 51 53	1 11	7 24	11.7	6.8
	Helgoland: Lighthouse	54 10 57	7 53 11	11 29	5 17	8.1	4.7
	Scharhorn: Beacon	53 57 15	8 24 35				
	Neuwerk: Lighthouse	53 55 01	8 29 58				
	Cuxhaven: Lighthouse	53 52 25	8 42 43	0 39	6 51	10.1	5.8
	Stade: Church steeple	53 36 12	9 28 48				
	Steinkirchen: Church	53 33 43	9 36 40	4 00	10 13	8.5	4.9
	Altona: Observatory	53 32 45	9 56 35				
	Hamburg: Old Observatory	53 33 07	9 58 27	5 00	11 12	6.1	3.5
	Imperial Marine Observatory	53 32 52	9 58 21				
	Berlin: Urania Observatory	52 31 31	13 21 52				
	Treptow Observatory	52 29 07	13 28 33				
	Harburg: Lighthouse	53 28 30	9 59 37				
	Hohe Weg: Lighthouse	53 42 50	8 14 48	0 25	6 38	10.1	5.7
	Langwarden: Church	53 36 20	8 18 30				
	Bremerhaven: New harbor light	53 32 52	8 34 25	0 54	7 07	10.4	5.8
	Minsener Sand: Light vessel	53 46 57	8 04 47	0 10	6 23	9.5	5.3
	Schillighorn: Lighthouse	53 42 21	8 01 43				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Germany.	Wilhelmshaven: Observatory	53 31 52	8 08 47	0 04	6 17	13.2	7.4
	Wangeroog: Lighthouse	53 47 25	7 54 09	11 27	5 15	8.0	4.5
	Spikeroog: Church	53 46 19	7 41 45				
	Langeoog: Belvedere	53 45 06	7 35 41				
	Balstrum: Church	53 43 46	7 22 03				
	Norderney: Lighthouse	53 42 39	7 13 58	11 05	4 53	7.3	4.1
	Juist: Church	53 40 45	6 59 53				
	Emden: City Hall tower	53 22 06	7 12 25	0 24	6 36	8.9	5.0
Denmark.	Falster: Gjedser light	54 33 50	11 58 03				
	Moen Island: Stege Church spire	54 59 03	12 17 16				
	Moen light, SE. pt	54 56 46	12 32 40				
	Prœste: Church spire	55 07 24	12 03 07				
	Kjorge: Church tower	55 29 44	12 07 36				
	Amager Island: Hollœnderby Ch. spire	55 35 45	12 38 24				
	Nordse Rase light	55 38 10	12 41 26				
	Copenhagen: University Observatory	55 41 13	12 34 41	9 33	3 21	0.6	0.3
	Bornholm: Ronne light	55 05 40	14 42 00				
	Christianso Island: Great tower	55 19 19	15 11 39				
	Kronberg: High spire	56 02 20	12 32 02				
	Nakkehooed: Upper light	56 07 10	12 20 50				
	Hesselo Island: Lighthouse	56 11 50	11 42 50				
	Anholt Island: Lighthouse	56 44 16	11 39 15				
	Spodsbjerg: Lighthouse	55 58 36	11 51 36				
	Roeskilde: Cathedral	55 38 34	12 05 02				
	Nykjobing: Church tower	55 55 30	11 40 29				
	Oddensby: Church tower	55 57 52	11 24 06				
	Sejro Island: Sejro Point light	55 55 09	11 05 07				
	Kallundborg: Church	55 40 50	11 05 04				
	Omo Island: Church	55 09 48	11 09 32				
	Vordingborg: Waldemar's tower	55 00 26	11 54 59				
	Veiro Island: Lighthouse	55 02 19	11 22 23				
	Langeland Island: Fakkebjerg light	54 44 23	10 42 13				
	Æro Island: Church spire	54 51 14	10 24 11				
	Lyo Island: Church tower	55 02 34	10 09 16				
	Assens: Church tower	55 16 09	9 53 50				
	Baago Island: Lighthouse	55 17 44	9 48 09				
	Kolding: Castle tower	55 29 31	9 28 40				
	Bogense: Church spire	55 34 03	10 05 29				
	Nyborg: Church spire	55 18 41	10 47 47				
	Turo Island: Church spire	55 03 00	10 40 02				
	Svendborg: Frue Church	55 03 37	10 36 48				
	Endelave Island: Church tower	55 45 32	10 16 20				
	Samso Island: Koldby Church tower	55 48 02	10 33 37				
	Horsens: Frelser Church spire	55 51 44	9 51 19				
	Tuno Island: Lighthouse	55 56 58	10 26 51				
	Samsoe Island: Nordby Church tower	55 57 06	10 33 00				
	Aarhus: Cathedral spire	56 09 26	10 12 50				
	Hjelm Islet: Lighthouse	56 08 00	10 48 32				
	Fornæs: Lighthouse	56 26 36	10 57 40				
	Hals: Church tower	56 59 54	10 18 53				
	Aalborg: St. Rudolph's Church	57 02 54	9 55 22				
	Cape Skaw, or Skagen: Old lighthouse	57 43 46	10 36 38	5 46	11 58	1.0	.05
	Hirtshals: Lighthouse	57 35 06	9 56 44	4 18	10 30	1.2	.07
	Haustholm: Lighthouse	57 06 50	8 36 10				
	Boobjerg: Lighthouse	56 30 48	8 07 23				
	Ringkjobing: Church spire	56 05 27	8 14 52				
	Loune: Church tower	55 47 17	8 14 36	2 35	8 47	2.1	1.2
	Blaabjerg: Summit, 100 ft	55 44 50	8 14 43				
	Guldager: Church	55 31 52	8 24 12	2 35	8 47	4.5	2.6
	Fano Island: Nordby Church	55 26 26	8 24 03	2 34	8 46	4.7	2.7
	Mano Island: Church spire	55 16 11	8 32 38				

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Holland.	Niewe Diep: Time-ball station	52 57 50	4 46 36	7 17	1 05	3.9	2.0
	Amsterdam: W. church tower	52 22 30	4 53 01				
	Utrecht: Observatory	52 05 10	5 07 45				
	Leyden: Observatory	52 09 20	4 29 03				
	The Hague: Church tower	52 04 40	4 18 30				
	Scheveningen: Lighthouse	52 06 16	4 15 10				
	Brielle: Lighthouse	51 54 29	4 10 45	2 50	9 02	4.8	2.5
	Rotterdam: Time-ball station	51 54 30	4 28 50	3 35	9 47	6.7	3.5
	Hellevoetsluis: Time-ball station	51 49 19	4 07 40	2 20	8 32	5.2	2.8
	Willemstadt: Lighthouse	51 41 48	4 26 26	3 20	9 32	9.8	5.2
	Goedereede: Light on church tower	51 49 08	3 58 35				
	Flushing: Time-ball station	51 26 33	3 35 48				
	Light, Westhaven bastion	51 26 24	3 34 32	0 44	6 56	14.7	7.8
Belgium.	Brussels: New observatory	50 47 56	4 21 44				
	Antwerp: Observatory	51 12 28	4 24 44	4 15	10 27	14.8	7.8
	Notre Dame Cathedral	51 13 17	4 24 12				
	Blankenberghe: Fort lighthouse	51 18 47	3 06 54	0 05	6 17	12.5	6.7
	Ostend: Lighthouse	51 14 13	2 55 51	0 02	6 32	16.1	8.4
	Church tower	51 13 50	2 55 22				
	Nieuport: Templars tower	51 07 53	2 45 34	0 10	6 22	15.7	8.4
France.	Paris: Observatory	48 50 11	2 20 15				
	Dunkerque: Tower	51 02 09	2 22 31	11 58	5 58	16.8	8.5
	Gravelines: Light on N. breakwater	51 00 18	2 06 34	11 59	6 16	19.0	9.6
	Calais: Light on old fort	50 57 45	1 51 07	11 39	6 13	21.0	10.7
	Cape Gris Nez: Lighthouse	50 52 10	1 35 02	11 17	5 51	21.5	11.0
	Boulogne, C. Alprech: Lighthouse	50 41 57	1 33 47	11 18	5 52	25.2	12.8
	Abbeville: Tower	50 07 05	1 49 56				
	Cayeux: Lighthouse	50 11 42	1 30 46				
	Dieppe: W. jetty light	49 56 06	1 05 01	10 54	5 48	27.3	13.3
	Ailly Point: Lighthouse	49 55 04	0 57 35				
	St. Valery en Caux: Light on W. breakwater	49 52 28	0 42 34	10 29	5 33	26.8	13.1
	Fécamp: N. jetty light	49 46 05	0 22 12	10 06	5 02	23.3	11.4
	Cape La Heve: S. light	49 30 04	0 04 08				
	Havre: S. jetty light	49 29 01	0 06 22	9 03	4 14	22.5	11.0
	Honfleur: Hospital jetty light	49 25 32	0 13 43				
			Long. W.				
	Caen: Church tower	49 11 14	0 21 10				
	Port Corseulles: W. jetty light	49 20 18	0 27 24				
	Point De Ver: Lighthouse	49 20 28	0 31 08				
	Cape La Hougue: Lighthouse	49 34 19	1 16 21	8 13	2 45	18.5	8.2
	Cape Barfleur: Lighthouse	49 41 50	1 15 56	8 14	2 37	17.0	7.5
	Cherbourg: Light, W. head of breakwater	49 40 29	1 43 44				
	Naval Observatory	49 38 54	1 38 08	7 30	1 44	17.6	7.8
	Cape La Hague: Lighthouse	49 43 22	1 57 15				
	Casquets Rocks: Light on NW. rock	49 43 17	2 22 41	6 20	0 15	15.5	6.9
	Port St. Peter, Guernsey: Light on Castle Coonet Breakwater	49 27 13	2 31 31	6 12	0 07	26.0	11.5
	Douvres Rocks: Lighthouse	49 06 28	2 48 49				
	Cape Carteret: Lighthouse	49 22 27	1 48 25	6 07	0 15	30.8	13.5
	Coutances: Cathedral tower	49 02 54	1 26 39				
	Granville: Lighthouse	48 50 07	1 36 46	5 50	0 09	36.7	16.0
	Chausey Is.: Light on SE. end of large id.	48 52 13	1 49 20	5 55	0 04	34.7	15.2
	St. Malo: Rochebourne light	48 40 18	1 58 41	5 43	0 04	36.0	15.7
	Cape Frehel: Lighthouse	48 41 05	2 19 08				
	Heau de Brehat: Lighthouse	48 54 33	3 05 11	5 35	12 00	30.4	13.3
	Morlaix, Ile Noire: Lighthouse	48 40 23	3 52 33	5 00	11 25	23.1	10.6
	De Bas Islet: Lighthouse	48 44 45	4 01 38	4 35	11 00	22.0	10.1
	Abervrach: Light on Vrach Islet	48 36 57	4 34 34	4 00	10 25	20.6	9.5
	Ushant: Stiff Point light	48 28 31	5 03 26	3 35	10 00	18.9	8.7

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		′ ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
France.	Brest: Observatory	48 23 32	4 29 36	3 23	9 45	19.5	9.0
	Brest (approach): Quelern light	48 19 10	4 34 28	......	......	......	....
	De Sein Islet: Lighthouse	48 02 40	4 52 03	3 25	9 53	17.2	7.9
	Bec du Raz: Lighthouse	48 02 28	4 45 25	......	......	......	....
	Audierne: Pierhead light	48 00 47	4 32 50	3 04	9 31	11.1	5.1
	Penmarch Rocks: Lighthouse	47 47 52	4 22 30	3 05	9 34	13.3	6.1
	Glenan Islands: Light, Penfret I	47 43 17	3 57 15	3 00	9 27	13.0	6.0
	De Groix Island: Lighthouse	47 38 51	3 30 35	......	......	......	....
	Lorient: Church-tower light	47 44 53	3 21 31	3 09	9 36	13.8	6.3
	Belle Isle: Lighthouse	47 18 42	3 13 38	3 25	9 50	16.6	7.7
	Port Haliguen: Light on N. jetty	47 29 10	3 06 09	3 35	9 58	16.9	7.9
	Haedic Island: Lighthouse	47 19 18	2 50 07	3 20	9 46	16.7	7.7
	Port Navalo: Lighthouse	47 32 53	2 55 08	3 45	10 08	16.6	7.7
	Vannes: St. Pierre Church	47 39 30	2 45 28	5 47	12 11	15.8	7.4
	Le Four Rock: Lighthouse	47 17 53	2 38 05	......	......	......	....
	Croisic: End of breakwater	47 18 30	2 31 25	3 25	9 47	16.7	7.7
	Guerande: Steeple	47 19 44	2 25 48	......	......	......	....
	Port St. Nazaire: Lighthouse	47 16 18	2 11 50	3 35	9 56	16.6	7.7
	Paimbœuf: Steeple	47 17 17	2 02 09	4 18	10 39	17.0	7.9
	Nantes: Cathedral	47 13 08	1 32 59	5 50	12 28	16.5	7.7
	Noir Moutier Island: Lighthouse	47 00 41	2 13 16	3 05	9 26	16.7	7.7
	Le Pilier Island: Lighthouse	47 02 35	2 21 37	......	......	......	....
	D'Yeu Island: Lighthouse	46 43 04	2 22 56	3 18	9 40	14.7	6.8
	La Chaume: Lighthouse	46 29 38	1 47 45	3 20	9 44	12.7	5.9
	Point de Grouin du Cou: Lighthouse	46 20 41	1 27 49	......	......	......	....
	Ré Island: Light, NW. pt	46 14 40	1 33 40	......	......	......	....
	Rochelle: E. Quay light	46 09 25	1 08 57	3 27	9 22	16.6	7.7
	Aix Island: Lighthouse	46 00 36	1 10 40	3 27	9 22	16.6	7.7
	Rochefort: Hospital	45 56 37	0 57 50	3 45	9 55	16.7	7.7
	Oleron Island: Light, NW. pt	46 02 49	1 24 37	......	......	......	....
	Point de la Coubre: Lighthouse	45 41 39	1 15 16	......	......	......	....
	Point Cordouan: Lighthouse	45 35 14	1 10 24	3 35	9 53	16.8	7.8
	Point de Grave: Lighthouse	45 34 10	1 04 27	......	......	......	....
	Bordeaux: University Obsy., Floirac	44 50 07	0 31 23	6 30	0 12	15.3	7.1
	Bayonne: Cathedral	43 29 29	1 28 43	......	......	......	....
	Biarritz: Lighthouse	43 29 38	1 33 16	......	......	......	....
	St. Jean de Luz: St. Barbe Point light	43 23 58	1 39 53	3 07	9 14	12.3	5.8
	Hendaye: Abbadia Observatory	43 22 52	1 45 02	......	......	......	....
Spain and Portugal.	Fuenterrabia: Light on Cape Higuera	43 23 30	1 47 30	......	......	......	....
	Port Pasages: Light at entrance	43 20 05	1 56 05	......	......	......	....
	San Sebastian: Monte Igueldo light	43 19 22	2 01 40	2 55	9 05	11.7	5.5
	Bilbao: Light on Galea Castle	43 22 36	3 04 06	2 50	9 03	12.7	5.9
	Castro Urdiales: Santa Ana Castle light	43 24 20	3 16 10	2 50	9 03	11.8	5.5
	Santoña: Pescador Point light	43 28 36	3 28 06	2 55	9 07	12.3	5.7
	Santander: Cape Mayor light	43 29 30	3 47 40	3 05	9 18	14.8	6.9
	San Martin de la Arena: Lighthouse	43 26 50	4 01 00	3 00	9 14	11.7	5.5
	San Vincent de la Barquera: End of new mole	43 23 35	4 24 55	3 00	9 14	10.4	4.9
	Rivadesella: Mount Somos light	43 31 00	5 07 10	......	......	......	....
	Gijon: Santa Catalina light	43 32 48	5 40 11	2 50	9 03	13.5	6.3
	Aviles: Lighthouse	43 38 05	5 56 00	2 45	8 58	12.0	4.9
	Rivadeo: Lighthouse	43 34 40	7 03 00	2 45	8 58	14.4	3.9
	Estaca Point: Lighthouse	43 47 20	7 42 00	......	......	......	....
	Port Cedeira: Lighthouse	43 39 00	8 05 30	2 43	8 56	14.8	6.1
	Ferrol: Old naval observatory	43 29 30	8 13 29	2 44	8 57	14.9	6.1
	Priorino Chico light	43 27 30	8 20 20	......	......	......	....
	Coruña: Hercules Tower light	43 23 10	8 24 26	2 43	8 56	14.8	6.1
	Cape Finisterre: Lighthouse	42 52 45	9 15 28	2 42	8 55	10.0	4.6
	Vigo: Cres I. light	42 12 30	8 54 00	......	......	......	....
	Oporto: Light, N. S. de Luz	41 09 10	8 40 35	2 25	8 38	10.0	4.3

MARITIME POSITIONS AND TIDAL DATA.

ATLANTIC COAST OF EUROPE—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range Spg.	Range Neap.
		° ′ ″	° ′ ″	*h. m.*	*h. m.*	*ft.*	*ft.*
Spain and Portugal.	Coimbra: Royal Observatory	40 12 25	8 25 47				
	Cape Mondego: Lighthouse	40 10 47	8 54 15	2 20	8 35	7.0	3.0
	Berlanga Island: Lighthouse	39 24 49	9 30 29				
	Peniche: Lighthouse	39 21 00	9 22 30	2 05	8 15	7.8	3.4
	Cape Roca: Lighthouse	38 46 49	9 29 46				
	Lisbon: Royal Observatory, Tapada	38 42 31	9 11 10	2 20	8 05	11.1	4.8
	Setubal: Lighthouse	38 29 15	8 56 00	2 10	8 20	11.6	5.0
	Cape St. Vincent: Lighthouse	37 01 20	8 58 00				
	Lagos: Church	37 07 48	8 39 53	1 55	8 08	13.0	5.6
	Cape Sta. Maria: Lighthouse	36 58 23	7 51 48				
	Ayamonte: Lighthouse	37 11 00	7 24 00				
	Huelva: Plaza at head of mole	37 15 08	6 57 12				
	San Lucar: Chipiona light	36 43 58	6 26 30	1 15	7 28	12.3	5.6
	Cadiz: Observatory of San Fernando	36 27 42	6 12 18				
	San Sebastian light	36 31 30	6 19 00	1 45	7 58	11.8	5.4
	Cape Trafalgar: Lighthouse	36 10 50	6 02 08				
	Tarifa: Lighthouse	35 59 53	5 36 31	1 32	7 52	5.6	2.6
	Algeciras: Verde I. light	36 07 19	5 26 12				
	Gibraltar: Dockyard flagstaff	36 07 10	5 21 17				
	Europa Pt. light	36 06 25	5 20 42	1 35	7 55	3.7	1.7

COASTS OF THE MEDITERRANEAN, ADRIATIC, AND BLACK SEAS.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range Spg.	Range Neap.
Spain.	Malaga: Lighthouse	36 42 39	4 24 38	2 15	8 35	2.9	1.5
	Almeria: Lighthouse	36 50 12	2 27 50				
	Cape de Gata: Lighthouse	36 42 57	2 11 12				
	Mazarron: Lighthouse	37 33 28	1 15 12				
	Cartagena: Arsenal gate	37 35 50	0 59 09				
	Escombrera light	37 33 22	0 57 58				
	Porman: Lighthouse	37 34 38	0 50 20				
	Santa Pola Bay: Lighthouse	38 12 30	0 30 12				
	Alicante: N. mole light	38 20 12	0 28 48				
	Villajoyose: Lighthouse	38 30 00	0 11 42				
	Benidonne: Tower	38 30 57	0 10 06				
	Altea: Lighthouse	38 33 30	0 04 02				
			Long. E.				
	Calpe: Church tower	38 38 36	0 02 52				
	Morayva: Tower	38 40 51	0 09 17				
	Jarea: Cape San Antonio light	38 48 06	0 12 02				
	Denia: Mole-head light	38 51 00	0 07 30				
			Long. W.				
	Cape Cullera: Lighthouse	39 12 15	0 13 37				
	Valencia: Lighthouse	39 28 05	0 19 48				
	Mole-end light	39 27 50	0 18 50	5 00	11 30	1.5	0.8
			Long. E.				
	Columbretes Islands: Lighthouse	39 53 57	0 41 19				
	Oropesa Cape: Lighthouse	40 04 53	0 08 56				
	Vinaroz: Mole-head light	40 27 48	0 28 48				
	Port Alfaques: Baña light	40 33 30	0 39 45				
	Cape Tortosa: Lighthouse	40 43 10	0 53 55				
	Tarragona: E. mole light	41 06 00	1 14 42				
	Barcelona: Royal Academy Obsy	41 25 18	2 07 00				
	Palamos Bay: Molino Pt. light	41 50 04	3 08 28				
	Cadaques: Clock tower	42 16 15	3 17 10				
	Cape Creux: Lighthouse	42 19 10	3 18 55				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

COASTS OF THE MEDITERRANEAN, ADRIATIC, AND BLACK SEAS—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
France.	Cape Bear: Lighthouse	42 30 59	3 07 30				
	Port Vendres: Fort Fanal light	42 31 18	3 06 50				
	Port Nouvelle: S. jetty light	43 00 47	3 04 08				
	Cette: Light, St. Louis mole	43 23 50	3 42 08				
	Aigues Mortes: Espignette Pt. light	43 29 17	4 08 32				
	Planier Rock: Lighthouse	43 11 57	5 13 51				
	Marseilles: Janet Cliff light	43 20 43	5 20 46	7 31	2 00	0.6	0.3
	National observatory	43 18 18	5 23 39				
	Ciotat: Berouard mole light	43 10 21	5 36 42				
	Toulon: St. Mandrien light	43 05 10	5 56 06	8 22	2 24	0.6	0.2
	Grand Riband Island: Lighthouse	43 01 01	6 08 39				
	Cannes: Lighthouse	43 32 51	7 00 54				
	Antibes: Garoupe light	43 33 51	7 08 02				
	Nice: Lighthouse	43 41 32	7 17 15				
	Villefranche: Mole-head light	43 41 58	7 18 42				
	Cape Ferret light	43 40 30	7 19 41				
Bal. I.	Port Ibiza: Lighthouse	38 54 10	1 27 25				
	Cabrera Island: Lighthouse	39 06 34	2 57 20				
	Pi (Majorca): Lighthouse	39 33 00	2 37 00				
	Port Mahon (Minorca): Lighthouse	39 51 53	4 18 20				
Sardinia.	Carloforte: Int. Latitude Obsy	37 08 09	8 18 44				
	Cape Spartivento: Lighthouse	38 52 34	8 51 08				
	Cape Sandalo: Light on San Pietro I	39 08 44	8 13 29				
	Porte Conte: Cape Caccia light	40 33 50	8 10 00				
	Port Torres: Lighthouse	40 50 25	8 23 56				
	Cape Testa: Lighthouse	41 14 36	9 08 42				
	Razzoli Island: Lighthouse	41 18 24	9 20 28				
	Caprera Island: Galera Pt	41 14 15	9 29 40				
	Cape Figari: Signal station	40 59 52	9 39 14				
	Cape Tavolara: Lighthouse	40 54 55	9 44 22				
	Cape Bellavista: Lighthouse	39 55 47	9 42 52				
	Cape Carbonera: Cavoli I. light	39 05 15	9 32 35				
	Cagliari: Light on mole	39 12 35	9 07 20				
Corsica.	Bonifacio: Mount Pertusato light	41 22 10	9 11 15				
	Ajaccio: Lighthouse	41 52 50	8 35 45				
	Corti: Church tower	42 18 14	9 09 04				
	Calvi: Lighthouse	42 35 10	8 43 25				
	Cape Corso: Giraglia I. light	43 01 45	9 24 10				
	Bastia: Lighthouse	42 41 47	9 27 00				
	Porto Vecchio: Chiape Pt. light	41 35 45	9 22 05				
Italy.	Cape Melle: Lighthouse	43 57 17	8 10 22				
	Genoa: San Benigno light	44 24 15	8 54 19				
	Hydro. Institute Obsy	44 25 09	8 55 20				
	Spezzia: Fort Santa Maria light	44 04 00	9 50 48				
	Florence: Arcetri Observatory	43 45 15	11 15 20				
	Leghorn (Livorno): Light on S. end of curved breakwater	43 32 36	10 17 45				
	Capraia Island: Cape Ferrajone light	43 02 57	9 51 07				
	Elba Island, Porto Longone: Cape Forcado light	42 45 14	10 24 38				
	Pianosa Island: Light on battery, W. side of fort	42 35 06	10 05 50				
	Africa Rock: Lighthouse	42 21 28	10 03 54				
	Monte Christo Islet: Summit	42 20 15	10 18 39				
	Giglio Island, Cape Rosso: Lighthouse	42 19 13	10 55 24				
	Civita Vecchia: Light N. end of breakwater	42 05 38	11 46 50				
	Rome: Royal Observatory at Capitol	41 53 34	12 29 06				
	Gaeta: Orlando tower	41 12 27	13 35 15				

MARITIME POSITIONS AND TIDAL DATA.

COASTS OF THE MEDITERRANEAN, ADRIATIC, AND BLACK SEAS—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Italy.	Ponza Islet: Punto della Guardia light	40 52 38	12 57 17				
	Naples: Observatory, Capo di Monte	40 51 46	14 15 26				
	Light on elbow of mole	40 50 20	14 15 37	4 00	10 13	0.7	0.2
	Capri Island: Carena Pt. light	40 32 07	14 11 40				
	Lipari Island: Casa Bianca light	38 28 43	14 51 40				
	Ustica Island: NE. point light	38 42 40	13 12 00				
	Faro of Messina: Capo di Faro light	38 16 02	15 39 11				
	Milazzo: Lighthouse	38 16 10	15 13 42				
	Palermo: Royal Observatory	38 06 44	13 21 29				
	Light on mole head	38 07 56	13 22 29				
	Trapani: Palumbo Rock light	38 00 39	12 29 50				
	Maritimo Island: Light on SW. pt	37 57 13	12 02 55				
	Marsala: W. mole light	37 47 10	12 25 59				
	Girgenti: Port Empedoche light	37 16 55	13 32 27				
	Gozo Island: Light on NW. pt	36 04 10	14 12 55				
	Malta Island, Valetta Harbor: Lighthouse	35 54 00	14 31 30	3 12	9 25	0.7	0.2
	Linosa Island: Landing Cove	35 51 50	12 52 09				
	Lampedusa Island: Carallo Bianco light	35 29 37	12 36 12				
	Cape Passaro: Lighthouse	36 41 03	15 07 45				
	Syracuse: Maniace Castle light	37 03 04	15 17 37				
	Augusta Port: Torre d'Avola light	37 12 39	15 13 20	3 00	9 13	0.9	0.3
	Catania: Sciari Biscari light	37 29 35	15 05 19				
	Royal University Observatory	37 30 13	15 05 00				
	Cape Taormina: Semaphore	37 50 25	15 18 30				
	Messina: San Ranieri light	38 11 32	15 34 33				
	Cape Peloro: Lighthouse	38 16 03	15 39 15				
	Cape Spartivento: Lighthouse	37 55 27	16 03 45				
	Cape Colonna: Lighthouse	39 01 29	17 12 09				
	Cotrone: Mole-head light	39 04 38	17 08 07				
	Taranto: Cape St. Vito light	40 24 41	17 12 23				
	Gallipoli: St. Andrea light	40 02 48	17 56 55				
	Cape Sta. Maria di Leuca: Lighthouse	39 47 43	18 22 17				
	Cape Otranto: Lighthouse	40 06 23	18 31 25				
	Port Otranto: Castle	40 09 06	18 28 45				
	Brindisi: Lighthouse	40 39 36	17 59 37	3 30	9 43	1.8	0.5
	Bari: St. Catalolo light	41 08 19	16 50 52				
	Viesti: Light on St. Croce Rock	41 53 17	16 11 13				
	Manfredonia: Lighthouse	41 37 39	15 55 34				
	Tremiti Islands: Caprara I. light	42 08 14	15 31 36				
	Ancona: Monte Cappucini light	43 37 14	13 31 18				
	Malamocco: Rocchetta Mole light	45 20 30	12 19 09	10 15	4 45	3.3	0.9
	Venice: Site of tower of St. Mark	45 26 02	12 20 24				
	Nautical Institute Observatory	45 26 11	12 20 32				
Austria.	Grado: Church tower	45 41 06	13 22 54				
	Monfalcone: Church tower	45 48 33	13 32 10				
	Trieste: Imperial Maritime Observatory	45 38 45	13 45 44				
	Theresa Mole light	45 38 54	13 45 14	9 20	3 50	2.0	0.6
	Capo d'Istria: Lighthouse	45 33 00	13 43 18				
	Isola: Lighthouse	45 32 34	13 39 32				
	Pirano: Lighthouse	45 31 54	13 33 48				
	Salvore Point: Lighthouse	45 29 24	13 29 30				
	Citta Nuova: Lighthouse	45 19 16	13 33 42				
	Parenzo: Cathedral tower	45 13 45	13 35 39				
	Rovigno: St. Eufemia light	45 05 00	13 38 00				
	Pola: Imperial Hydro. Office Obsy	44 51 49	13 50 43	9 00	3 25	3.4	0.9
	Promontore Point: Porer Rock light	44 45 30	13 53 36				
	Nera Point: Lighthouse	44 57 24	14 08 42				
	Fiume: Cathedral tower	45 19 36	14 26 41	8 15	2 35	1.2	0.3
	Porto Re: Lighthouse	45 16 18	14 33 42				
	Veglia: Mole head	45 01 30	14 34 36				
	Prestenizza Point: Lighthouse	45 07 12	14 16 30				
	Cherso: Kimen Point light	44 57 36	14 23 30				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

COASTS OF THE MEDITERRANEAN, ADRIATIC, AND BLACK SEAS—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Austria.	Galiola Rock: Lighthouse	44 43 36	14 10 36				
	Unie Island: Netak Point light	44 37 20	14 14 06				
	Lussin Piccolo: Manora Observatory	44 32 11	14 28 06	8 10	2 25	1.1	0.3
	St. Pietro di Nembo Island: Health office	44 27 42	14 33 28				
	Gruizza Rock: Lighthouse	44 24 42	14 34 06				
	Zengg: Mole-head light	44 59 24	14 53 48				
	Terstenik Rock: Lighthouse	44 40 06	14 34 42				
	Carlobago: Lighthouse	44 31 30	15 04 24				
	Zara: Church tower	44 07 05	15 14 05				
	Bianche Point: Lighthouse	44 09 06	14 49 24				
	Zara Vecchia: Church tower	43 56 16	15 26 21				
	Port Tajer: Lestrice I. light	43 51 15	15 12 06				
	Lucrietta Island: Lighthouse	43 37 36	15 34 24				
	Sebenico: Mount Tartaro	43 45 08	15 58 07	6 10	0 20	1.0	0.3
	Rogosnizza Port: Mulo Rock light	43 31 00	15 55 00				
	Zirona Grande Island: St. George Church tower	43 27 00	16 08 51				
	Trani: Cathedral tower	43 31 02	16 15 09				
	Port Spalato: Cathedral tower	43 30 07	16 26 06				
	Solta I., Port Olivetto: St. Nicholas tower	43 23 50	16 11 10				
	Spalato Passage: Speo Pt. light	43 19 12	16 24 30				
	Makarska: Church tower	43 17 46	17 01 36				
	Pomo Rock: Center	43 05 28	15 27 30				
	St. Andrea Rock: Summit	43 01 43	15 45 29				
	Lissa Island: Hoste Rock light	43 04 30	16 12 28	4 00	10 30	2.4	0.7
	Pakonjidol Rock: Lighthouse	43 09 24	16 27 14				
	Lesina Island: Port Gelsa light	43 09 50	16 41 55				
	St. Giorgio Pt. light	43 07 30	17 12 00				
	Sabioncello Peninsula: Cape Gomena light	43 02 50	17 00 19				
	Sorelle Rocks: Lighthouse	42 57 42	17 12 44				
	Curzola Island: Porto Bema mole head	42 54 19	16 51 32				
	Porto Valle Grande, church tower	42 57 37	16 43 07				
	Lagostini Island: Glavat Rock light	42 45 54	17 08 54				
	Lagosta Island: St. George Chapel	42 45 05	16 51 45				
	Cazza Island: Lighthouse	42 45 05	16 29 29				
	Pelagosa Rock: Lighthouse	42 23 30	16 15 12				
	Meleda Island: Port Palazzo Ruin	42 47 06	17 22 51				
	Olipa Rock: Lighthouse	42 45 30	17 46 48				
	Pettini di Ragusa Rocks: Lighthouse	42 39 00	18 03 08				
	Bobara Rock: Summit	42 35 08	18 10 49				
	Molonta Peninsula: Summit	42 27 04	18 25 36				
	Ostro Point: Lighthouse	42 23 36	18 32 00				
	Cattaro: Health office	42 25 30	18 46 12				
	Budua: Mole-head light	42 16 42	18 50 36				
	Katic Rock: St. Domenica Chapel	42 11 43	18 56 25				
	Antivari: Pt. Valovica light	42 05 15	19 04 19				
	Dulcigno: W. windmill	41 55 47	19 12 29				
Albania.	Cape Rodoni: Guardhouse	41 35 10	19 27 15				
	Cape Pali: Guardhouse	41 23 31	19 24 54				
	Durazzo: Lighthouse	41 18 40	19 27 14				
	Cape Laghi: Ruin	41 08 44	19 26 47				
	Skumbi River: Pyramid at mouth	41 02 12	19 26 30				
	Semeny River: Samana Pt. light	40 47 00	19 20 14				
	Vojazza River: Pyramid at mouth	40 36 14	19 19 14				
	Avlona: Lighthouse	40 25 30	19 27 55				
	Cape Linguelta: Extreme	40 25 17	19 17 45				
	Mount Cica: Pyramid	40 12 00	19 38 33				
	Port Palermo: Pyramid	40 02 57	19 47 53				
	Cape Kiefali: Pyramid	39 54 29	19 54 55				

MARITIME POSITIONS AND TIDAL DATA.

COASTS OF THE MEDITERRANEAN, ADRIATIC, AND BLACK SEAS—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Saseno Island: Lighthouse	40 30 12	19 16 15				
	Fano Island: Pt. Kastri light	39 51 53	19 26 06				
	Port Pagonia: Ruin	39 39 27	20 07 12				
	Port Gomenitza: Well Dogana	39 29 50	20 17 09				
	Port Parga: Madonna I	39 16 32	20 24 55				
	Port St. Spiridione: Convent	39 39 54	19 43 09				
	Corfu: Lighthouse	39 37 05	19 56 30				
	Paxo Island: Madonna I. light	39 11 30	20 12 34				
	Prevesa; Fort Nuovo minaret	38 56 30	20 45 40				
	Port Drepano: Observation island	38 47 25	20 44 16				
	Port Vliko: Customhouse	38 40 40	20 42 44				
	Port Vathi: Lazaretto light	38 22 04	20 43 37				
	Port Argostoli: St. Theodoro light	38 11 36	20 29 30				
	Patras: Lighthouse	38 15 00	21 43 50	3 40	9 53	1.0	0.3
	Katakolo: Lighthouse	37 38 20	21 18 55				
	Zante: Mole light	37 47 10	20 55 26				
	Strovathi, or Strivali Island: Stamphani I. light	37 15 12	21 01 14				
	Proti Passage: Marathon Pt	37 03 38	21 34 35				
	Navarin: Lighthouse	36 54 10	21 40 29				
	Mothoni: Round tower	36 48 40	21 42 40				
	Koroni Anchorage: Mole light	36 47 50	21 58 00				
	Petalidi Bay: Petalidi Pt	36 57 20	21 56 42				
	Candia Island, Port Suda: Lighthouse	35 28 55	24 09 39				
	Megalo Kastron: Mole light	35 20 30	25 09 44				
	Kandeliusa Island: Lighthouse	36 29 40	26 59 25				
	Stampali Island, Maltezana Port: Agios Ioanes	36 34 25	26 24 28				
	Christiana Islands: N. pt	36 15 20	25 13 00				
Greece.	Milo Island: Summit, Mt. St. Elias	36 40 27	24 23 15				
	Siphano Island: Lighthouse	36 59 12	24 40 30				
	Naxos Island, Naxia: Gate on Bacchus I.	37 06 32	25 23 00				
	Paros Island, Port Trio: Trio Pt	37 00 01	25 14 21				
	Port Naussa: St. Yanni Church	37 08 38	25 14 08				
	Syra: Mole light	37 26 12	24 56 14				
	Sermo Island: Amyno Pt	37 07 36	24 32 23				
	Thermia Island: Ruins of Cythnus	37 25 55	24 23 35				
	Jura Island: North pt	37 38 00	24 44 32				
	Port St. Nikolo: Lighthouse	37 39 28	24 19 44				
	St. Nikalao Island: Port Mandri	37 44 00	24 04 12				
	Andros Island, Cape Fasse: Lighthouse	37 57 30	24 42 30				
	Ieraka: Acropolis	36 47 05	23 05 40				
	Port Kheli: Lighthouse	37 18 42	23 08 53				
	Poros Island: Lighthouse	37 31 45	23 25 45				
	Ægina: Lighthouse	37 44 30	23 25 30				
	Piræus: Lighthouse	37 56 14	23 38 10				
	Athens: National Observatory	37 58 21	23 43 14				
	Cape Colonna: Extreme	37 38 45	24 02 15				
	Port Raphti: Statue I	37 52 48	24 03 00				
	Petali Island: Trago I. peak	38 01 28	24 16 42				
	Euripo Strait: Lighthouse	38 28 15	23 36 45				
	Skiathos Island: Mount Stavros	39 10 48	23 27 07				
	Salonika: S. bastion	40 37 28	22 58 00				
	Lemnos Island: Kastro Castle	39 52 10	25 03 20				
	Port Moudros: Sangrada Pt	39 50 52	25 14 14				
	Strati Island: St. Strati Church	39 31 58	24 59 13				
	Mityleni Island, Port Sigri: Lighthouse	39 12 35	25 50 00				
	Mityleni: Light on Mityleni Pt	39 06 10	26 34 54				
	Port Iero: Sidero Islet	39 03 20	26 31 39				
	Psara Island: Fort	38 32 00	25 35 00				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

COASTS OF THE MEDITERRANEAN, ADRIATIC, AND BLACK SEAS—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Turkey.	Port Baklar: Cape Xeros	40 32 40	26 45 00				
	Port Isene: Tower	37 16 33	27 36 55				
	Samos Island: Fonia Pt. light	37 41 24	26 58 42				
	Tchesmé: C. Kécil light	38 19 55	26 17 45				
	Kos: Lighthouse	36 55 00	27 18 25				
	Marmorice Harbor: Adassi Pt. light	36 48 00	28 18 00				
	Makry Harbor: Kasil I.	36 39 33	29 06 13				
	Rhodes Port: Arab's Tower light	36 26 00	28 16 24				
	Port Lindo: Tower	36 05 53	28 08 10				
	Dardanelles: Hellas Pt. light	40 02 30	26 10 54				
	Gallipoli: Lighthouse	40 24 27	26 41 24				
	Bosphorus: Tofana Pt. light	41 01 20	29 01 00				
	Scutari: Leander Tower light	41 01 02	29 00 29				
	Constantinople: Seraglio Pt. light	41 00 35	29 01 14				
	St. Sophia Mosque	41 00 16	28 58 59				
	Cape Kara Burnu: Lighthouse	41 21 15	28 42 14				
Russia.	Yuiada Road: Fort Tersana	41 52 04	27 58 45				
	Burghaz: Lighthouse	42 27 52	27 35 54				
	Varna Bay: Lighthouse	43 10 00	27 58 35				
	Kusterjeh: Cape Kusterjeh light	44 10 20	28 39 14				
	Danube River: Salina light	45 09 47	29 41 14				
	Fidonisi Island: Lighthouse	45 16 00	30 14 14				
	Odessa: University Observatory	46 28 37	30 45 32				
	Nikolaieff: Naval Observatory	46 58 22	31 58 27				
	Dnieper Bay: Fort Nikolaeo light	46 34 27	31 33 36				
	Sebastopol: E. lighthouse	44 36 55	33 36 26				
	Balaklava Bay: Hospital	44 29 50	33 36 25				
	Kertch: Lighthouse	45 21 03	36 28 30				
	Berdiansk: Breakwater light	46 45 00	36 46 40				
	Saukhoum: Lighthouse	42 58 00	40 55 10				
Turkey.	Batoum: Lighthouse	41 39 30	41 38 15				
	Trebizond: Lighthouse	41 01 00	39 46 25				
	Sinope: Lighthouse	42 01 20	35 13 20				
	Bender Erekli: Lighthouse	41 18 03	31 25 49				
	Marmora Island: Light off E. pt.	40 38 10	27 46 09				
	Artaki Bay: Zeitijn Adasi Islet	40 23 30	27 47 30				
	Tenedos Island: Ponente Pt. light	39 50 00	25 58 34				
	Port Ajano: Nikolo Rock	39 01 21	26 47 57				
	Port Ali-Agha: W. pt. of entrance	38 50 10	26 57 20				
	Smyrna: English consulate flagstaff	38 25 40	27 09 10	9 15	3 15	2.5	0.7
	Vourlah: Customhouse	38 21 48	26 47 00				
	Sighajik Harbor: Beacon on islet	38 12 21	26 47 32				
	Budrum: Lighthouse	37 02 00	27 27 05				
	Adalia: Lighthouse	36 52 00	30 45 34				
	Alexandretta: Lighthouse	36 35 30	36 10 20				
	Latakia: Lighthouse	35 30 30	35 46 30				
	Tripoli Roadstead: Bluff Islet light	34 29 25	35 44 24				
	Ruad Island: Lighthouse	34 52 00	35 51 00				
	Beirut: Lighthouse	33 54 10	35 28 25	9 45	3 35	1.2	0.3
	Saida (ancient Sidon): Lighthouse	33 34 20	35 21 30				
	Sûr (ancient Tyre): Lighthouse	33 16 30	35 14 40				
	Acre: Lighthouse	32 54 35	35 08 00				
	Haifa: Lighthouse	32 47 40	35 05 00				
Cyprus.	Famagusta: Lighthouse	35 07 10	33 57 22	9 40	3 30	1.4	0.4
	C. Gata: Light	34 33 45	33 01 30				
	Larnaka: Lighthouse	34 54 00	33 38 59				
Egypt.	Port Said: High lighthouse	31 15 41	32 18 45	9 40	3 30	1.0	0.3
	River Nile: Damietta Mouth	31 31 40	31 51 00				
	Rosetta Mouth light	31 29 30	30 19 10				
	Aboukir Bay: Nelson I. peak	31 21 23	30 06 00				
	Alexandria: Eunostos Pt. light	31 11 43	29 51 40	9 45	3 15	1.1	0.3

MARITIME POSITIONS AND TIDAL DATA.

COASTS OF THE MEDITERRANEAN, ADRIATIC, AND BLACK SEAS—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Ben Ghazi: Castle	32 06 51	20 02 40	9 55	3 45	1.2	0.3
	Tripoli Harbor: Lighthouse	32 54 03	13 10 50	10 00	3 50	1.9	0.5
Tunis.	Sfax: Ras Tina light	34 39 01	10 41 17	3 35	9 57	4.2	1.1
	Mehediah: Sidi Jubber	35 30 24	11 05 15				
	Monastir: Burj el Kelb battery	35 45 24	10 50 42				
	Hammamet Bay: Castle flagstaff	36 23 20	10 37 10				
	Kalibia Road: Lighthouse	36 50 12	11 07 00				
	Cape Bon: Lighthouse	37 04 45	11 03 15				
	Tunis: Goletta light	36 48 19	10 18 31	3 33	9 55	3.0	0.8
Algeria.	Cape Farina: Extreme	37 10 42	10 17 30				
	Benzert: N. Jetty light	37 16 38	9 53 21				
	Galita Island: Monte Guardia	37 31 16	8 56 12				
	Bona: Fort Genois light	36 57 15	7 46 40				
	Stora: Singe I. light	36 54 29	6 53 11				
	Cape Bougaroni: Lighthouse	37 05 17	6 28 37				
	Cape Carbon: Lighthouse	36 46 41	5 06 22				
	Algiers: Lighthouse near Admiralty	36 47 16	3 04 13	2 46	8 58	2.6	1.3
	Bouzareah Observatory	36 47 50	3 02 08				
	Cape Tenez: Lighthouse	36 33 07	1 20 36				
			Long. W.				
	Oran: Mers el Kebir light	35 44 21	0 41 38				
	Habibas Island: Lighthouse	35 43 22	1 07 57				
Morocco.	Zafarin Islands: Light Isabel Segunda I.	35 11 05	2 25 45				
	Alboran Island: Lighthouse	35 58 00	3 03 29				
	Ceuta: Lighthouse	35 53 44	5 16 46	1 55	8 07	3.3	1.5
	Tangier: Casbah tower	35 47 00	5 48 31	1 30	7 40	8.0	3.7
	Cape Spartel: Lighthouse	35 47 14	5 55 41				

WEST COAST OF AFRICA.

Coast.	Place.	Lat. N.	Long. W.	H. W.	L. W.	Spg.	Neap.
	El Araish: S. pt. of entrance	35 12 50	6 09 13				
	Sali: Fort	34 04 10	6 48 00	1 35	7 45	10.4	4.8
	Cape Dar el Beida: Lighthouse	33 36 00	7 33 00				
	Cape Blanco, North: Extreme	33 08 00	8 35 05				
	Mogador Harbor: English consulate	31 30 30	9 43 30	1 05	7 17	10.9	5.0
	Cape Ghir: Extreme	30 38 00	9 50 00				
	Cape Noun: Extreme	28 45 00	11 02 00				
	Cape Juby: Extreme	27 56 00	12 56 00	11 55	5 43	8.5	3.9
	Cape Bojador: Extreme	26 07 57	14 29 00	11 50	5 38	7.3	3.4
	Penha Grande	25 07 06	14 50 44				
	Ouro River entrance: Dumford Pt	23 36 03	15 58 00				
	Pedra de Galha	22 12 37	16 48 11				
	Cape Blanco: Extreme	20 46 27	17 05 40	11 35	5 23	5.5	2.5
	Portendik: Village	18 18 45	16 02 00				
	St. Louis: Lighthouse	16 01 31	16 30 22				
	Almadie Point: Lighthouse	14 44 45	17 32 25				
	Cape Verde: Lighthouse	14 43 20	17 30 55				
	Port Dakar: Lighthouse	14 40 30	17 25 28				
	Cape Manoel: Lighthouse	14 38 55	17 26 47				
	Goree Island: Fort	14 39 55	17 24 30				
	Bird Island: Flagstaff	13 39 45	16 40 30				
	Bathurst: Flagstaff	13 28 00	16 35 00	9 00	2 50	5.9	2.7
	Carabane: Lighthouse	12 35 00	16 44 00				
	Nunez River: Sand I	10 36 37	14 42 00				
	Ponga River entrance: Observation Pt	10 03 15	14 04 30	7 30	1 20	11.4	5.2
	Isles do Los: Lighthouse	9 30 30	13 44 00				
	Matacong Island: House	9 16 10	13 26 20				
	Scarcies River: W. end of Yellaboi I	8 57 05	13 18 25				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF AFRICA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Sierra Leone: Light on cape	8 30 00	13 18 30	7 40	1 30	11.6	5.3
	N. battery	8 29 57	13 14 30	....	....	....	....
	Sherbro Island: N. island	7 40 36	13 04 30	....	....	....	....
	Sherbro River: Manna Pt	7 22 45	12 31 55	5 50	12 00	10.4	4.8
	Gallinas River: W. elbow of Kamasoun I.	7 00 08	11 38 45	....	....	....	....
	Cape Mount: W. peak	6 44 30	11 22 51	....	....	....	....
	Cape Mesurado: Lighthouse	6 19 10	10 49 25	....	....	....	....
	Monrovia: Lighthouse	6 19 00	10 50 00	5 40	11 54	6.0	2.5
	Marshall: Agent's house	6 08 06	10 22 45	....	....	....	....
	Grand Bassa: Agent's house	5 54 08	10 04 05	....	....	....	....
	Cestos: Factory	5 26 25	9 34 45	....	....	....	....
	Sangwin River: Sangwin Pt	5 12 42	9 20 16	....	....	....	....
	Sinon: Bloobarra Pt	4 59 15	9 02 05	4 50	11 05	4.8	2.0
	Cape Palmas: Lighthouse	4 22 10	7 44 15	4 30	10 43	4.3	1.8
	Tabou River: Tabou Pt	4 24 47	7 21 30	....	....	....	....
	Axim Bay: Ft. St. Anthony	4 52 18	2 14 45	....	....	....	....
	Cape Three Points: Lighthouse	4 45 00	2 05 45	4 00	10 13	4.7	1.9
	Dix Cove: Fort	4 47 45	1 56 40	....	....	....	....
	Tacorady Bay: Tacorady Pt	4 53 00	1 45 00	....	....	....	....
	Chama Bay: Dutch Fort	5 01 00	1 38 00	....	....	....	....
	El Mina Bay: Ft. St. George	5 04 48	1 21 05	....	....	....	....
	Cape Coast Castle: Lighthouse	5 06 20	1 13 50	4 20	10 32	6.0	2.5
	Accra: Lighthouse	5 31 50	0 11 30	....	....	....	....
			Long. E.				
	Volta River entrance: Dolbens Pt	5 46 00	0 41 00	4 20	10 33	4.2	1.8
	Lagos River: Lighthouse	6 25 15	3 25 15	4 50	11 05	3.3	1.3
	Benin River entrance: N. pt	5 46 01	5 03 05	....	....	....	....
	Brass River: Entrance (approx.)	4 16 40	6 15 00	....	....	....	....
	Calebar River (New): Rough Corner	4 23 07	7 07 00	....	....	....	....
	Opobo River: W. pt. beacon (approx.)	4 27 00	7 40 00	....	....	....	....
	Quaebo River: Bluff Pt	4 30 40	7 59 00	....	....	....	....
	Calebar River (Old): Judicial Ho. flagstaff (Duke Town)	4 57 53	8 18 57	....	....	....	....
	Fernando Po Island: Lighthouse	3 46 10	8 47 05	....	....	....	....
	San Bento River: Joho Pt. (approx.)	1 35 00	9 39 00	....	....	....	....
	Princes Island: Diamond Rocks, center of largest	1 40 42	7 27 56	....	....	....	....
	St. Thomas Island: Ft. San Sebastian light	0 20 30	6 42 45	....	....	....	....
		Lat. S.					
	Anno Bon Island: Turtle Islet	1 24 18	5 38 12	....	....	....	....
	Cape Lopez: Lighthouse	0 36 25	8 43 10	....	....	....	....
	Mayumba Bay: Lighthouse	3 23 00	10 38 00	4 25	10 38	7.0	2.9
	Loango Bay: Indian Pt. light	4 40 00	11 46 30	4 13	10 26	6.5	2.7
	Black Point Bay: Sandy Pt	4 49 00	11 45 00	....	....	....	....
	Malemba Bay: Landing Cove	5 18 30	12 08 00	....	....	....	....
	Kabenda Bay: Kabenda Pt. light	5 32 30	12 11 00	....	....	....	....
	Congo River entrance: Shark Pt	6 04 36	12 15 00	4 10	10 25	6.0	2.5
	Margate Head: Summit	6 31 50	12 25 25	....	....	....	....
	St. Paul de Loando: Flagstaff, Ft. San Miguel	8 48 24	13 13 20	3 40	9 53	4.8	2.0
	Lobito Point: Extreme	12 20 00	13 32 00	....	....	....	....
	Benguela: Telegraph office	12 34 43	13 23 45	3 30	9 43	5.5	2.3
	Elephant Bay: Friar Rocks	13 12 30	12 48 55	....	....	....	....
	St. Mary Bay: Bay I	13 26 05	12 36 00	....	....	....	....
	Little Fish Bay: Lighthouse	15 09 00	12 12 00	....	....	....	....
	Port Alexander: Bateman Pt	15 47 30	11 52 40	....	....	....	....
	Great Fish Bay: Tiger Pt	16 30 00	11 42 00	3 00	9 12	5.7	2.4
	Cape Frio: Extreme	18 23 00	11 57 12	....	....	....	....
	Walfisch Bay: Lighthouse	22 57 00	14 30 00	....	....	....	....
	Ichabo Island	26 17 00	14 57 20	....	....	....	....
	Angra Pequena: Diaz Pt	26 37 52	15 07 02	....	....	....	....
	Elizabeth Bay: S. pt. of Possession I	26 58 30	15 12 22	2 35	8 47	5.5	2.3

MARITIME POSITIONS AND TIDAL DATA.

WEST COAST OF AFRICA—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	North Nolloth: Magistrate's house	29 15 12	16 52 02	2 25	8 38	5.3	2.2
	Hondeklip Bay	30 18 33	17 16 20	......	......	......	....
	Roodewal Bay	30 33 07	17 27 30	......	......	......	....
	Saldanha Bay: Constable Hill	33 07 51	18 01 21	2 20	8 33	5.1	2.1
	Table Bay: Robben I. light	33 48 52	18 22 33	......	......	......	....
	Cape Town: Royal Observatory	33 56 04	18 28 41	1 36	7 47	4.6	2.0
	Cape of Good Hope: Lighthouse	34 21 12	18 29 26	......	......	......	....

EAST COAST OF AFRICA AND THE RED SEA.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
	Simons Bay: Lighthouse	34 10 45	18 27 30	2 35	8 48	5.2	2.2
	Cape Hangklip: Extreme	34 23 48	18 50 20	......	......	......	....
	Quoin Point: Extreme	34 46 45	19 38 17	......	......	......	....
	Cape Agulhas: Lighthouse	34 49 45	20 00 37	2 40	8 53	5.2	2.2
	Port Beaufort: Flagstaff	34 23 47	20 48 40	......	......	......	....
	St. Blaize: Lighthouse	34 11 10	22 09 31	3 18	9 31	5.6	2.0
	Knysna Harbor: Fountain beacon	34 04 35	23 03 38	......	......	......	....
	Plettenberg Bay: Summit of Seal Pt	34 06 15	23 24 23	......	......	......	....
	St. Francis: Lighthouse	34 12 30	24 50 20	......	......	......	....
	Cape Recife: Lighthouse	34 01 41	25 42 12	......	......	......	....
	Port Elizabeth: Lighthouse	33 57 43	25 37 21	3 21	9 33	5.4	1.9
	Bird Islands: Lighthouse	33 50 27	26 17 13	......	......	......	....
	Port Alfred: Signal staff	33 36 09	26 54 10	......	......	......	....
	Waterloo Bay: Maitland Signal Hill	33 28 00	27 03 00	......	......	......	....
	Madagascar Reef: Center	33 23 10	27 20 48	......	......	......	....
	Cove Rock: Center	33 05 10	27 49 12	......	......	......	....
	East London: Lighthouse	33 01 45	27 55 02	3 37	9 50	5.0	1.8
	Cape Morgan: Extreme	32 42 00	28 22 36	......	......	......	....
	Hole-in-the-Wall	32 02 30	29 06 40	......	......	......	....
	Rame Head: Extreme	31 48 15	29 21 15	......	......	......	....
	Cape Hermes: Extreme	31 38 06	29 33 16	......	......	......	....
	Waterfall Bluff	31 26 15	29 48 40	......	......	......	....
	Port Natal (Durban): Lighthouse	29 52 40	31 03 41	3 58	10 11	5.6	1.6
	Govt. Observatory	29 50 47	30 00 18	......	......	......	....
	Dumford Point: Extreme	29 00 12	31 51 39	......	......	......	....
	Cape St. Lucia: Extreme	28 32 30	32 27 39	......	......	......	....
	Cape Vidal: Extreme	28 09 36	32 38 10	......	......	......	....
	Delagoa Bay: Pta. Vermelha (Reuben Pt.) light	25 58 30	32 35 55	5 10	11 22	11.9	3.4
	Cape Corrientes: Small rock	24 05 30	35 29 45	......	......	......	....
	Innamban Bay: Barrow Hill light	23 45 30	35 31 41	4 30	10 42	11.0	3.2
	Cape St. Sebastian: Extreme	22 05 00	35 29 00	......	......	......	....
	Bazaruto Island: N. pt. light	21 31 00	35 29 30	......	......	......	....
	Chuluwan Island: Lighthouse	20 38 10	34 53 30	......	......	......	....
	Sofala: Fort on N. side of entrance	20 10 42	34 46 00	......	......	......	....
	Zambesi River: Kangoni Mouth	18 52 50	36 11 47	4 15	10 27	13.5	3.9
	Kiliman River: Lighthouse	18 01 24	36 58 30	......	......	......	....
	Kiliman: Town	17 51 50	37 01 09	......	......	......	....
	Mazemba River: Entrance	17 15 00	38 04 00	......	......	......	....
	Premeira Islands: Center of Casuarina I.	17 06 30	39 06 27	......	......	......	....
	Angoxa Islands: Center of Hurd I	16 33 24	39 49 57	......	......	......	....
	Mafamale Island: Center	16 20 30	40 03 57	......	......	......	....
	Port Mokambo: Mokambo Pt	15 08 00	40 36 12	......	......	......	....
	Port Mozambique: St. George I. light	15 02 12	40 48 45	......	......	......	....
	San Sebastian light	15 00 45	40 45 06	4 00	10 12	11.8	3.4
	Cape Cabeceira: Lighthouse	14 58 20	40 45 10	......	......	......	....
	Port Conducia: Bar Pt	14 53 00	40 40 00	......	......	......	....
	Lurio Bay: Pando Pt	13 23 40	40 46 00	......	......	......	....
	Pemba Bay: N pt. light	12 55 45	40 31 15	......	......	......	....
	Querimba Islands: Ibo I. light	12 19 30	40 40 09	......	......	......	....
	Numba Island: E. pt	11 09 18	40 43 21	......	......	......	....

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF AFRICA AND THE RED SEA—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Cape Delgado: Lighthouse	10 41 20	40 38 35	3 59	10 11	11.3	3.3
	Msimbati: Ras Matunda	10 19 22	40 26 34	......	......	......	....
	Mikindini Harbor: Kinizi	10 16 31	40 10 33	......	......	......	....
	Mgan Mwania: Madjori Rock	10 06 43	40 02 14	......	......	......	....
	Lindi River: Fort flagstaff	9 59 30	39 46 41	3 55	10 08	10.9	4.5
	Mchinga Bay: Observation spot	9 44 22	39 47 07	......	......	......	....
	Kiswere Harbor: Rustmigi	9 25 36	39 39 31	......	......	......	....
	Kilwa Kisiwani: Fort	8 57 15	39 30 42	......	......	......	....
	Mafia Island: Moresby Pt	7 38 10	39 54 42	......	......	......	....
	Dar-Es-Salaam: Flagstaff	6 49 41	39 17 05	......	......	......	....
	Bagamoyo: French Mission	6 26 10	38 54 27	......	......	......	....
	Zanzibar: English consulate	6 09 43	39 11 08	4 05	10 17	14.5	6.0
	Tanga Bay: Lighthouse	5 00 35	39 10 20	......	......	......	....
	Mombasa: Lighthouse	4 04 30	39 41 13	......	......	......	....
	Port Melinda: Vasco de Gama's Pillar	3 12 48	40 11 21	4 00	10 13	12.1	5.0
	Lamo Bay: Lamo Castle	2 15 42	40 56 21	......	......	......	....
	Manda Roads: E. side of Manda Toto I.	2 13 35	40 59 40	......	......	......	....
	Port Durnford: Foot Pt	1 13 00	41 54 15	4 30	10 42	11.7	4.9
	Kisimayu Bay: S. pt. of Kisimayu I	0 22 35	42 33 57	......	......	......	....
		Lat. N.					
	Brava: Well	1 06 48	44 03 27	4 15	10 27	7.5	3.1
	Meurka Anchorage: S. pt. of town	1 42 06	44 53 49	......	......	......	....
	Magadoxa: Tower	2 01 48	45 24 39	......	......	......	....
	Murat Hill: Peak	2 30 00	46 07 00	......	......	......	....
	Ras Hafun: E. extreme of Africa	10 26 30	51 22 55	......	......	......	....
	Cape Guardafui: E. pt	11 50 30	51 16 45	6 00	12 12	6.1	2.5
	Kal Farun Islet: Center	12 26 00	52 09 35	......	......	......	....
	Abd-al-Kuri Island: NE. pt	12 11 15	52 25 35	......	......	......	....
	Sokotra Island: Tamarida, mosque	12 39 00	53 59 31	7 05	1 17	7.5	3.1
	Ras Antareh: Extreme of rocky pt	11 27 30	49 35 40	......	......	......	....
	Mait Island: Center	11 13 00	47 17 00	......	......	......	....
	Port Berbera: Lighthouse	10 25 00	44 59 35	......	......	......	....
	Zeyla: Mosque	11 22 00	43 29 35	7 30	1 18	8.5	3.5
	Perim Island: Lighthouse	12 39 00	43 25 35	7 50	1 38	7.2	3.0
Red Sea.	Hanfelah Bay: Hanfelah Pt	14 44 00	40 52 00	......	......	......	....
	Disei Island: Village Bay	15 28 10	39 45 30	......	......	......	....
	Massaua Harbor: N. pt. of entrance	15 37 12	39 27 23	0 45	6 57	4.0	1.7
	Khôr Nowarat: Shatireh Islet	18 15 12	38 19 30	......	......	......	....
	Suakin: Lighthouse	19 07 00	37 19 09	2 10	8 22	1.7	0.7
	Makaua Island: S. pt	20 44 00	37 15 30	......	......	......	....
	St. Johns Island: Peak	23 36 20	36 10 15	......	......	......	....
	Dædalus Shoal: Lighthouse	24 56 30	35 51 00	......	......	......	....
	Kosair Anchorage: SW. angle of fort	26 06 24	34 17 03	......	......	......	....
	Brothers Island: Lighthouse	26 18 50	34 50 45	6 40	0 28	2.0	0.8
	Safajah Island: N. summit	26 45 48	33 59 43	......	......	......	....
	Ashrafi Island: Lighthouse	27 47 21	33 42 28	......	......	......	....
	Ras Gharib: Lighthouse	28 20 52	33 06 31	10 35	4 23	1.5	0.6
	Zafarana: Lighthouse	29 06 29	32 39 43	10 40	4 28	5.5	2.3
	Suez: Newport Rock	29 53 05	32 32 50	10 45	4 32	6.8	2.8
	Tôr: Ruined fort	28 13 47	33 36 56	......	......	......	....
	Sherm Yahar: Entrance	27 35 45	35 30 30	......	......	......	....
	Sherm Joobbah: Entrance	27 33 00	35 32 30	......	......	......	....
	Sherm Wej: Lighthouse	26 13 00	36 27 00	......	......	......	....
	Sherm Hassey: Anchorage	24 38 35	37 17 45	......	......	......	....
	Yembó: Anchorage	24 05 15	38 02 45	......	......	......	....
	Sherm Rabegh: Anchorage	22 43 50	39 00 30	......	......	......	....
	Jiddah: Jezirah el Mifsaka I	21 28 00	39 10 38	3 30	9 42	2.0	0.8
	Lith: Agha Islet	20 09 00	40 12 00	......	......	......	....
	Jelalil: Anchorage	19 55 30	40 30 00	......	......	......	....
	Kunfidah: Islet	19 07 40	41 03 20	......	......	......	....
	Khôr Nohud: Entrance	18 15 50	41 27 30	......	......	......	....

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF AFRICA AND THE RED SEA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Red Sea.	Farisan I. Anchorage: Jebel Mandhakh	16 50 15	41 58 15				
	Gizau: Fort	16 53 00	42 29 00				
	Loheiya: Hill Fort	15 42 00	42 38 45	1 15	7 27	2. 9	1. 2
	Kamarán Bay: Harbor	15 20 30	42 34 00				
	Hodeïda Road	14 47 00	42 56 00				
	Jebel Zukur Island: N. pt	14 03 53	42 45 28				
	Mokha: N. Fort	13 19 43	43 13 36	11 45	5 33	4. 5	1. 9

ISLANDS OF THE INDIAN OCEAN.

Coast.	Place.	Lat. N.	Long. E.	H. W.	L. W.	Spg.	Neap.
Laccadive Islands.	Chitlac Islet: S. end	11 40 45	72 42 54				
	Betrapar Islet: N. Island	11 35 00	72 09 54				
	Kittan Islet: S. end	11 27 30	72 59 00	10 20	4 00	6. 3	3. 0
	Cardamum Islet: Center	11 13 00	72 44 00				
	Ameni Islet: N. end	11 06 00	72 41 00				
	Underut Islet: Center	10 47 00	73 40 00				
	Cabrut Islet: E. end	10 32 00	72 37 40				
	Seuheli Par: N. islet	10 06 00	72 15 10				
	Kalpeni Islet: S. end	10 03 00	73 35 54				
	Minikoi Island: Lighthouse	8 16 00	73 01 15	11 27	5 15	2. 5	1. 2
Maldive Islands.	Heawandu Island: S. end	6 55 00	72 55 54				
	Kee-lah Island: N. end	6 59 00	73 12 54				
	Mah Kundu Island: NE. extreme	6 25 00	72 41 54				
	Nar Foree Island	5 26 30	73 20 00				
	Hee-tah-doo Island	5 01 30	72 53 00				
	To-du Island: Center	4 25 45	72 57 24				
	Gafor Island: Center	4 44 00	73 28 00				
	Malé, or Kings Island: Flagstaff	4 10 15	73 30 24	0. 20	6 25	2. 9	1. 4
	Pha-li-du Island: Northern end	3 41 00	73 24 54				
	Moluk Island: Center	2 57 00	73 34 24				
	Himmittee Island	3 16 00	72 48 00				
	Kimbeedso Island: S. end	2 10 30	73 03 00				
	Esdu Island: NE. pt	2 07 00	73 35 54				
	Wahdu Island: E. end	0 14 30	73 13 00				
		Lat. S.					
	Addu Atoll: Gung I	0 41 30	73 06 54				
	Amirante Islands: Ile des Roches, N. beach	5 40 56	53 41 03				
	African Islands	4 52 26	53 23 38				
	Seychelles, Platte I.: S. end	5 53 00	55 27 10				
	Port Victoria: End of Hodoul Jetty	4 37 15	55 27 23	4 22	10 35	4. 3	1. 2
	Bird Island: Tree	3 43 06	55 12 19				
	Chagos Archipelago, Peros Banhos: Diamond Islet	5 15 00	71 43 47				
	Diego Garcia: N. end of Middle I	7 13 37	72 23 50	1 30	7 43	5. 8	1. 7
	Cargados Carajos: Establishment I., flagstaff	16 25 12	59 46 40	1 50	8 03	4. 0	1. 2
	Rodriguez Island: Mathurina Bay, Point Venus	19 40 22	63 25 38	0 20	6 32	5. 5	1. 6
Mauritius I.	Flat Island: Lighthouse	19 52 36	57 39 14				
	Cannonier Point: Lighthouse	19 59 45	57 32 35				
	Port Louis: Martello tower, Ft. George	20 08 46	57 29 26	0 48	7 00	1. 6	0. 3
	Royal Alfred Obsy	20 05 39	57 33 09				
	Grand Port: Fouquet I. light	20 24 20	57 47 14				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE INDIAN OCEAN—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Réunion Island: St. Denis light	20 51 38	55 26 59				
	Bel-Air light	20 53 11	55 36 18				
	St. Paul light	20 59 45	55 16 18				
	St. Pierre light	21 19 47	55 28 58	11 50	5 38	3.5	0.6
	Tromelin Island: N. end	15 51 37	54 28 46				
	Agalegas Island: NW. pt	10 21 30	56 32 00				
	Farquhar Islands: Hall's house	10 06 45	51 10 21				
	Alphonse Island: SE. part (Trees)	7 00 30	52 44 57				
	Coetivy Island: N. end	7 06 00	56 22 00				
Madaga	Cape St. Mary: S. extreme	25 39 10	45 06 50				
	Leven Island: Center	25 12 30	44 17 57				
	Port Machikora: Barracouta I	25 03 00	44 07 20				
	St. Augustine Bay: Nosi Vei I	23 38 25	43 38 20	5 40	11 52	9.8	2.9
	Murderers Bay: Center of Murder I	22 05 18	43 15 20				
	Cape St. Vincent: Extreme	21 54 24	43 20 21				
	Mourondava: Village	20 18 18	44 19 21				
	Tsmano: Village	19 49 30	44 31 30				
	Kovra Rythi Point: Extreme	17 53 00	44 02 20				
	Coffin Island: Nosi Vao	17 29 00	43 45 18				
	Cape St. Andrew: Extreme	16 12 10	44 29 05				
	Boyanna Bay: Barabata Pt	16 07 00	45 17 09				
	Cape Tauzon: Extreme	15 46 30	45 43 09				
	Majunga (Mojanga): Lighthouse	15 43 45	46 18 45	4 15	11 28	10.9	3.2
	Majamba Bay: W. pt	15 11 42	46 57 29				
	Narendri Bay: Moormora Pt	14 40 18	47 24 36				
	Port Radama: Pt. Blair	13 59 00	47 58 21				
	Radama Islands: N. pt. Nossuvee I	13 55 40	47 48 05				
	Baratoube Bay: Ambubuka Pt	13 27 15	47 59 30				
	Nosi Bé: Hellville Jetty	13 23 38	48 17 34				
	Minow Islands: N. pt. Great I	12 49 30	48 38 57				
	Cape San Sebastian: Extreme	12 27 20	48 45 45				
	Port Liverpool: N. pt. of entrance	12 03 18	49 11 21				
	Cape Amber: NE. extreme	11 57 30	49 17 25				
	Port Lady Frances: Sunson Pt	12 23 20	49 35 56				
	Port Looké: Pt. Bathurst	12 44 02	49 45 06				
	Port Leven: S. pt. Nosi Hau I	12 49 00	49 54 00				
	Andrava Bay: Berry Head	12 56 48	49 56 25				
	Vohemar: Flagstaff	13 21 15	50 01 59				
	Cape East: Ugoncy I	15 15 48	50 31 21				
	Venangue Bé Bay: Entrance	15 54 50	50 16 05				
	Port Choiseul: Maran Seelzy Village	15 27 55	49 49 11	3 45	9 57	5.1	1.5
	Cape Bellone: Extreme	16 14 00	49 50 59				
	St. Marys Island: Light on Madame I	17 00 05	49 50 59				
	Port Tantang: Flagstaff	16 42 30	49 56 15				
	Fenerive Point: Flagstaff	17 23 16	49 32 04				
	Tamatave: Pt. Hastie	18 09 47	49 25 31	4 00	10 12	7.3	2.1
	Mahanuru: Town	19 55 00	48 52 10				
	Matatane: Village	21 58 10	48 14 50				
	Santa Lucia: N. end of town, Obs. Rock	24 46 25	47 10 34				
	Point Ytapere: Extreme	24 59 42	47 07 20				
	Ytapere Bay: N. pt	24 58 50	47 04 24				
	Fort Dauphin: Flagstaff	25 01 30	46 59 11	4 15	10 27	4.7	1.3
	Europa Island: Center	22 22 30	40 24 10				
	Bassas da India: E. pt	21 29 00	39 40 39				
	Geyser Reef: SE. extreme	12 26 30	46 32 35				
	Mayotta Island: Zaoudzi	12 47 02	45 16 27	4 00	10 13	11.9	2.0
	Johanna Island: Landing place, Pomoni Harbor	12 16 20	44 24 54				
	Mohilla Island: Numa Choa Harbor	12 25 00	43 47 00				
	Glorioso Islands: W. islet	11 34 48	47 24 09				
	Comoro Island: Islet in Mauroni Bay	11 40 44	43 19 15	4 45	10 58	10.0	1.7
	Assumption Island: Hummock	9 46 20	46 31 07				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE INDIAN OCEAN—Continued.

Coast.	Place.	Lat. S	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Aldabra Island: West I., E. side entrance	9 22 35	46 14 52				
	Cosmoledo Islands: Observation islet	9 41 20	47 32 25				
	Prince Edwards Islands: Marion I., Obs. spot, NE. side	46 49 30	37 49 15				
Crozet Is.	Penguin Islands Center of SW. islet	46 36 00	50 41 30				
	Possession Island: NW. pt	46 22 00	51 30 15				
	Twelve Islands: Summit NE. I	46 01 00	50 40 00				
	Navire Bay	46 28 18	51 50 00				
	Hog Island: Summit	46 10 40	50 35 00				
	East Island: Center	46 26 00	52 13 00				
Kerguelen Is.	Christmas Harbor	48 40 00	69 04 00				
	Blighs Cape	48 26 45	68 48 20				
	Cape Bourbon	49 42 00	68 54 00				
	Molloy, Port Royal Sound: U. S. Tr. of Venus Obs., 1874	49 21 22	70 04 31	0 14	6 36	4.6	1.3
	Cape Challenger	49 41 00	70 15 00				
	Balfour Rock	49 29 00	70 29 50				
	Heard Island: Cape Laurens, NW. end	53 02 45	73 15 30				
	Sealing station	53 13 00	73 52 00				
	McDonald Island, Summit	53 02 50	72 31 45				
	St. Pauls Island: Ninepin Rock	38 42 51	77 31 53	10 40	4 28	3.0	0.9
	Amsterdam Island: Summit, 2,750 feet	37 50 00	77 29 15	10 50	4 38	3.3	1.0
	Keeling or Cocos Islands: Direction I	12 06 22	96 53 02	5 20	11 32	5.1	1.5
	Christmas Island: Flying Fish Cove	10 25 19	105 45 57	7 10	1 00	4 5	1.3

SOUTH COAST OF ASIA.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
Arabia.	Aden: Telegraph station	12 47 16	44 59 07	7 49	1 41	4.9	2.0
	Sughra: Sheik's house	13 22 00	45 40 50				
	Mokatein: Black ruin	13 24 50	46 26 35				
	Howaiyuh: Sheik's house	13 28 45	46 39 00				
	Banderburum: SE. house of town	14 20 10	48 56 45				
	Makalleh Bay: Flagstaff	14 31 15	49 07 35	8 20	2 07	6.8	2.8
	Shahah Roads: Customhouse	14 43 50	49 35 05				
	Sharmoh: Single house	14 49 00	49 57 05				
	Kosair: High house	14 54 40	50 16 35				
	Sihut: Center of town	15 12 00	51 10 30				
	Ras Fartak: Extreme pt	15 38 00	52 14 20				
	Damghot: Town	16 30 00	52 48 00				
	Merbat: Town	16 59 00	54 43 29	8 50	2 38	7.0	2.9
	Kuria Maria Is., Hullaniyeh I.: NE. bluff	17 32 45	56 03 05				
	Ras Sherbedat: Point	17 53 15	56 20 35				
	Cape Isolette: Islet	19 00 25	57 51 35				
	Masirah Island: Point Abu-Rasas	20 10 00	58 38 35				
	Point Ras Ye	20 31 30	58 58 35	9 45	3 32	9.6	4.4
	Ras-al-Hed: Extreme pt	22 32 40	59 48 35	9 15	3 03	8.9	4.1
	Maskat (Muscat): Maskat Pt	23 38 00	58 30 50	9 30	3 20	6.0	2.8
	Deimaniyeh Islands: E. islet	23 52 00	58 08 00				
	Sueik: Fort	23 51 30	57 26 00				
	Sohar: SE. tower of town hall	24 21 50	56 46 12				
	Khor Fakan Bay: W. end of village	25 21 00	56 22 56				
	Ras Musendom: N. end of island	26 24 13	56 32 22				
	Great Quoin Islet: Center	26 30 00	56 31 29				
	Sharjah: High tower with flagstaff	25 21 34	55 24 12				
	Abu-Thabi: Fort flagstaff	24 29 02	54 22 14				
	Al Beda'a Harbor: Nessah Pt., N. extreme	25 17 24	51 33 32				
	Ras Rakkin: NW. pt	26 10 55	51 13 46				
	Bahrein Harbor: Portuguese fort	26 13 56	50 31 18	5 15	11 30	6.4	3.7
	Basrah: Customhouse flagstaff	30 32 00	47 51 23				
	Kuweit Harbor: N. end of town	29 22 56	48 00 55	0 05	6 17	8.3	4.8

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

SOUTH COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Persia.	Kàhrig Islet: Fort flagstaff	29 15 25	50 21 11				
	Abu Shahr: Residency flagstaff	28 59 07	50 50 35	7 12	1 13	2.6	1.5
	Shaikh Shu'aib Islet: E. end	26 47 40	53 23 36				
	Kais Islet: NE. pt	26 33 37	54 02 21	0 30	6 40	6.6	3.8
	Bàsidù: Chapel	26 39 12	55 16 47				
	Hanjam Islet: Ruined mosque	26 40 49	55 54 25				
	Kasm: Fort	26 57 27	56 17 37	10 50	4 35	11.6	5.3
	Jask Bay: Telegraph office	25 38 19	57 45 57	9 20	3 05	7.8	3.6
	Kub Kalat: High peak, 1,680 feet	25 29 45	59 40 32				
	Chahbar Bay: Telegraph office	25 16 43	60 37 40				
	Gwatar Bay: Islet	25 03 17	61 26 24				
Baluchistan.	Gwadar Bay: Telegraph office	25 07 19	62 19 42	9 20	3 05	8.1	3.7
	Pasni: Telegraph office	25 15 52	63 28 37				
	Ormarah: Telegraph office	25 11 55	64 37 02				
	Sunmiyani: Jam's house	25 25 19	66 35 39	8 50	2 35	8.1	3.8
	Cape Monze: Peak	24 50 03	66 39 58				
India.	Karachi: Manora light	24 47 37	66 58 06	10 15	4 00	7.3	3.4
	Observatory	24 49 50	67 01 33				
	Mandavi: Lighthouse	22 50 00	69 20 15				
	Beyt (Bet): Lighthouse	22 29 20	69 05 15	12 05	5 39	10.8	5.2
	Dwarka: Lighthouse	22 14 00	68 57 06				
	Temple spire	22 14 00	68 58 54				
	Porbandar: Lighthouse	21 38 00	69 36 00				
	Mangarol: Lighthouse	21 06 00	70 06 32				
	Diu Head: Lighthouse	20 41 20	70 50 45				
	Kutpur: Lighthouse	21 02 21	71 49 35				
	Bhaunagar: Lighthouse	21 47 00	72 14 00	4 27	11 18	29.8	15.1
	Perim Island: Lighthouse	21 35 54	72 21·08				
	Cambay: Flagstaff	22 17 00	72 35 10				
	Surat River: Tapti light	21 05 20	72 38 40				
	Surat: Minaret Adrusah	21 12 19	72 49 27				
	Bassein: Center of town	19 20 10	72 48 44				
	Bombay: Colaba Observatory	18 53 45	72 48 56	11 26	5 08	12.0	4.9
	Kenery Island light	18 42 08	72 48 49				
	Bankot: Fort Victoria	17 58 00	73 02 40				
	Ratnagherry: Fort	16 59 30	73 15 56				
	Viziadrug: Fort Flagstaff	16 33 26	73 19 39				
	Cape Ramas: W. bastion of fort	15 05 12	73 54 50				
	Goa: St. Denis Church	15 21 24	73 54 00				
	Aguada light	15 29 25	73 46 10	10 34	4 10	5.2	2.5
	Vingorla: Signal-station light	15 51 10	73 37 00				
	Vingorla Rocks: Lighthouse	15 53 20	73 27 15				
	Sedashigar Bay: Oyster Rock light	14 49 00	74 03 40	10 34	4 11	5.0	2.4
	Kumpta: Lighthouse	14 25 00	74 22 30				
	Hinàwar: Monument	14 17 28	74 26 40				
	Kundapur: Lighthouse	13 38 15	74 39 50				
	Mangalore: Lighthouse	12 52 17	74 50 40	10 50	4 28	6.5	3.4
	Kannanur: Lighthouse	11 51 10	75 21 51				
	Tellicherri: Flagstaff	11 45 00	75 29 40				
	Mahè: Lighthouse	11 42 00	75 31 10				
	Calicut: Lighthouse	11 15 10	75 46 40	11 21	4 59	2.7	1.4
	Cochin: Lighthouse	9 58 00	76 14 40	11 33	5 06	2.1	1.0
	Alipee: Lighthouse	9 30 00	76 20 40				
	Quilon: Tangacherri Point light	8 53 20	76 34 00	0 18	6 16	2.5	1.3
	Trivandrum: Observatory	8 30 47	76 56 45				
	Tiruchendore: Pagoda on pt	8.29 55	78 07 47				
	Cape Comorin: Lighthouse	8 04 00	77 32 35				
	Tuticorin: Lighthouse	8 47 10	78 11 26	1 52	7 51	3.0	0.8
	Pamban Pass: Lighthouse	9 17 20	79 12 50	1 37	7 36	2.0	0.5

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

SOUTH COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Ceylon.	Manaar: Center of town	8 59 00	79 53 52				
	Colombo: Lighthouse	6 55 40	79 50 40	1 55	7 49	2. 0	0. 4
	Dondra Head: Lighthouse	5 55 30	80 34 12				
	Point de Galle: Lighthouse	6 01 25	80 13 04	2 02	8 07	1. 9	0. 4
	Great Bassas Rocks: Lighthouse	6 10 10	81 28 15				
	Little Bassas Rocks: Lighthouse	6 25 00	81 44 00				
	Batticaloa: Lighthouse	7 45 00	81 41 00				
	Trincomali: Dock-yard flagstaff	8 33 30	81 13 42	8 10	1 44	2. 0	0. 5
India.	Calimere Point: Lighthouse	10 18 00	79 51 30				
	Negapatam: Lighthouse	10 45 28	79 50 47	8 37	2 37	2. 1	0. 9
	Pondicherri: Lighthouse	11 55 40	79 50 10				
	Madras: Observatory	13 04 08	80 14 55				
	Lighthouse	13 05 15	80 17 27	8 41	2 26	3. 1	1. 2
	Pulicat: Lighthouse	13 25 15	80 19 12				
	Armeghon: Lighthouse	13 53 08	80 12 30				
	Kistna: Lighthouse	15 47 00	80 59 00				
	Masulipatam: Flagstaff	16 09 45	81 11 00				
	Coconada: Lighthouse	16 56 21	82 15 05	8 42	2 35	4. 5	1. 9
	Vizagapatam: Fort flagstaff	17 41 34	83 17 42	8 48	2 34	4. 4	1. 8
	Kalingapatam: Lighthouse	18 19 00	84 07 30				
	Gopalpur: Lighthouse	19 13 00	84 52 06				
	Gaujam: Fort	19 22 30	85 03 29				
	Juggernath: Great temple	19 48 17	85 49 09				
	False Point: Lighthouse	20 20 20	86 44 00	9 21	3 00	6. 8	2. 6
	Balasor River: Chandipur light	21 27 15	87 02 20				
	Saugor Island: Lighthouse	21 38 40	88 02 00				
	Diamond Harbor: Flagstaff	22 11 10	88 11 07				
	Calcutta: Ft. William semaphore	22 33 25	88 20 12	1 25	9 06	11. 2	4. 4
Burma.	Chittagong River: Lighthouse	22 11 00	91 49 00	1 02	7 56	13. 1	5. 6
	Akyab: Oyster Reef light	20 05 00	92 39 00				
	Old temple	20 08 53	92 52 40	9 40	3 28	7. 6	3. 0
	Ramree Island: S. pt	18 51 00	93 56 30				
	Chedubah Island: NW. peak	18 50 30	93 31 00				
	Cape Negrais: Extreme	16 01 30	94 13 16				
	Bassein River: Alguada Reef light	15 42 14	94 12 00				
	Bassein: Port Dalhousie	16 01 30	94 23 00	3 05	9 55	18. 7	7. 8
	Andaman Is.: Table Id., Lighthouse	14 12 30	93 22 30				
	Port Cornwallis, Rock in entrance	13 18 40	92 57 10	9 50	3 37	8. 6	2. 9
	Port Blair, Lighthouse	11 40 40	92 45 15	9 40	3 27	6. 3	2. 1
	Little Andaman Island, SE. pt	10 27 00	92 31 10				
	Krishna Shoal: Light vessel	15 37 26	95 37 32				
	Rangoon River: Grove Pt. light	16 30 01	96 23 00				
	Rangoon: Great Dagon pagoda	16 46 00	96 07 30	4 26	11 15	16. 9	7. 0
	Moulmein: Docks	16 26 00	97 38 00	3 07	10 49	11. 7	5. 0
	Moulmein River: Amherst Pt. light	16 04 45	97 33 05	2 12	8 49	19. 2	7. 4
	Double Island: Lighthouse	15 52 00	97 35 00				
	Tavoy River: Lighthouse	13 36 40	98 13 00	10 50	4 20	15. 6	5. 9
	Mergui: Courthouse	12 26 15	98 35 59	10 40	4 10	18. 0	6. 9
	Tenasserim	12 06 00	99 03 00				
	St. Matthew Island: Hastings Harbor	10 05 05	98 10 15				
	Pak Chan River: Lighthouse	9 58 00	97 35 00				
Malaysia.	Tongka Harbor, Junkseylon Island: Lighthouse	7 50 00	98 25 30				
	Pulo Penang: Fort Cornwallis	5 24 45	100 21 44	11 50	5 40	8. 8	3. 8
	Dinding Channel: Hospital Rock	4 13 05	100 34 15				
	One Fathom Bank: Lighthouse	2 52 10	100 59 12	5 50	12 00	14. 4	6. 2

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

SOUTH COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Malaysia.	Cape Rachado: Lighthouse	2 24 08	101 51 02	......	......	......	....
	Malakka: Stat. St. Pauls Hill	2 11 30	102 15 00	7 20	1 08	10.5	4.5
	Singapore Strait: Coney Island light	1 09 57	103 44 47	......	......	......	....
	Singapore: Cathedral tower	1 17 33	103 51 11	10 18	4 02	7.6	3.2
	Singapore Strait: Pedra Branca light	1 19 57	104 24 08	......	......	......	....
	Summit Bintang great hill, 1,253 feet	1 04 20	104 27 21	......	......	......	....
	Rhio Straits, Pulo Sauh: Lighthouse	1 03 13	104 10 30	......	......	......	....
	Terkolei: Lighthouse	0 57 10	104 19 52	......	......	......	....
	Little Garras: Lighthouse	0 44 30	104 21 19	9 40	3 14	7.1	3.1
	Rhio, Bintang Island: Residency flagstaff	0 55 50	104 25 43	......	......	......	....
	Pitong Island: Peak	0 36 52	104 04 42	......	......	......	....
	Abang Besar Island: N. pt	0 36 30	104 11 31	......	......	......	....
		Lat. S					
	Linga Island: Flagstaff	0 12 34	104 36 14	6 00	12 13	11.5	4.9
	Singkep Island: Mountain summit	0 26 13	104 30 15	......	......	......	....
	Menali Island: N. pt	0 57 51	105 38 20	......	......	......	....
		Lat N.					
	Nicobar Islands, Car Nicobar: N. pt	9 15 40	92 48 00	......	......	......	....
	Nicobar Islands, Nancowry Harbor: Naval Pt	8 02 10	93 29 42	9 05	2 52	8.3	2.8
	Great Nicobar: W. pt. Galathea Bay	6 46 20	93 49 20	......	......	......	....
Sumatra.	Acheen (Acheh) Head: Pulo Bras light	5 45 00	95 04 33	......	......	......	....
	N. extreme	5 34 40	95 19 00	10 00	3 44	5.2	2.3
	Diamond Point: Lighthouse	5 15 58	97 30 11	11 50	5 34	8.7	3.7
		Lat. S.					
	Point Baru or Datu: Extreme	0 00 32	103 47 58	......	......	......	....
	Point Bon or Djabon: Extreme	1 00 55	104 21 30	......	......	......	....
	Moeara-Kompehi: Fort	1 23 13	103 59 14	......	......	......	....
	Djambi: Flagstaff of fort	1 35 33	103 36 41	......	......	......	....
	Palembang: Residency flagstaff	2 59 26	104 45 34	......	......	......	....
	Lampong Bay: Telok Betong light	5 27 00	105 15 58	......	......	......	....
	Blimbing Bay	5 55 02	104 32 36	5 40	11 52	2.6	0.7
	Kroë: Village	5 11 24	103 55 42	......	......	......	....
	Engano Island: Barioe anchorage	5 18 50	102 07 28	......	......	......	....
	Bintœan: River mouth	4 48 35	103 20 18	......	......	......	....
	Mega Island: N. pt	3 59 25	101 00 58	......	......	......	....
	Benkulen: Lighthouse	3 47 22	102 14 50	5 50	12 03	4.0	1.1
	Bantal: Village	2 44 54	101 17 25	......	......	......	....
	Indrapura Point: Extreme	2 10 35	100 50 06	......	......	......	....
	Pisang: Lighthouse	0 59 56	100 19 28	......	......	......	....
	Padang: Lighthouse	0 57 53	100 20 19	5 35	11 48	5.5	1.4
	Siberoet Island: Sigeb Pt	0 53 58	98 53 58	......	......	......	....
	Katiagam: Village	0 07 41	99 45 20	......	......	......	....
	Batoe Islands: N. point of Simoe Islet	0 03 13	98 05 55	......	......	......	....
	Summit of Tello	0 02 56	98 16 43	......	......	......	....
		Lat. N.					
	Ayer Bangis: Fort flagstaff	0 11 41	99 22 09	5 29	11 42	2.8	0.7
	Natal: Fort flagstaff	0 33 11	99 06 33	......	......	......	....
	Nias Island: Lagoendi Bay	0 34 47	97 43 43	......	......	......	....
	Sitoli	1 17 36	97 36 46	......	......	......	....
	Lapan	1 24 16	97 12 28	......	......	......	....
	Siboga: Flagstaff	1 44 24	98 46 08	......	......	......	....
	Singkel: Post office	2 16 47	97 45 06	......	......	......	....
	Bangkaru Islands: Bay	2 02 32	97 06 53	......	......	......	....
	Simaloe Island: NW. pt	2 51 30	95 56 02	......	......	......	....
	Tampat Toewon: Flagstaff	3 14 59	97 10 13	......	......	......	....
	Analaboe	4 08 14	96 07 23	......	......	......	....
	Batoe Toetong: Landing place	4 38 21	95 34 29	......	......	......	....

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Banka Strait.	Java Head: First Pt. light	6 44 30	105 11 48	5 30	11 42	2.5	0.7
	Sunda Strait: Krakatoa I. peak	6 08 46	105 26 58	6 50	0 37	3.8	1.1
	North Watcher Island: Lighthouse	5 12 17	106 27 33				
	Lucipara I.: Beacon	3 13 05	106 13 02				
	Banka Island: Tobol Ali Fort	3 00 48	106 27 22	[9 05]	[2 52]	[10.1]	
	Berikat, summit	2 34 18	106 50 36				
	Nanka I.: Lighthouse	2 23 20	105 44 30	[6 50]	[0 38]	[9.3]	
	Banka Island: Mintok light	2 04 03	105 09 45				
	Blinyu	1 38 26	105 46 28				
	Crassok Pt	1 29 00	106 57 30				
Gaspar Strait.	Shoalwater Island: Lighthouse	3 19 10	107 12 42	[2 08]	[8 21]	[5.6]	
	Pulo Lepar: Lighthouse	2 56 52	106 54 38				
	Pulo Jelaka: Lighthouse	2 52 05	107 00 43				
	Billiton Island: Tanjong Pandan flagstaff	2 44 40	107 38 46				
	Langkuas I. light	2 32 12	107 37 15	[3 17]	[9 29]	[6.6]	
	Gaspar Island: Peak	2 24 30	107 03 33				
Entrance to China Sea.	Carimata Island: Sharp peak	1 33 24	108 55 13				
	Pulo Eu: Center	2 07 00	104 17 00				
	Pulo Aor: S. peak, 1,805 feet	2 26 30	104 34 06				
		Lat. N.					
	St. Barbe Island: Center of W. side	0 07 26	107 13 00				
	Direction Island: S. pt	0 14 19	108 01 47				
	Dato Island: Summit	0 06 37	108 37 05				
	St. Julian Island: Summit	0 55 00	106 45 00				
	Tambelan Island: S. pt	0 56 52	107 32 57				
	Tamban I. obs. station	1 00 27	106 24 10				
	Victory Island: S. pt	1 34 41	106 18 27				
	Anamba Islands: White rock	2 18 10	105 35 58				
	Pulo Repon	2 25 00	105 52 00				
	Pulo Domar	2 44 31	105 22 57				
	St. Pierre Rock: S. pt	1 51 42	108 38 55				
	Natuna Islands: Pyramidal rocks	4 03 00	107 21 40				
	Semione I	4 31 00	107 42 30				
		Lat. S.					
Java.	Anjer: Fourth Pt. light	6 04 15	105 53 05	7 11	0 58	2.4	0.7
	Bantam: Flagstaff	6 01 20	106 08 20				
	Batavia: Observatory	6 07 40	106 48 37	[11 58]	[5 46]	[3.0]	
	Buitenzorg: Palace tower	6 35 45	106 49 11				
	Boompjeo Island: Racket I. light	5 56 15	108 22 37				
	Cheribon: Lighthouse	6 43 00	108 34 00				
	Tegal: Flagstaff	6 51 09	109 08 07				
	Pekalongan: Light W. of entrance	6 51 29	109 41 08				
	Samarang: Lighthouse	6 57 09	110 25 03	[6 00]	[12 13]	[4.0]	
	Rembang: Residency flagstaff	6 42 18	111 20 32				
	Surabaya: Time-ball station	7 12 10	112 43 58	12 07	5 54	4.9	1.7
	Pasuruan: Lighthouse	7 37 30	112 55 00	11 44	5 31	6.2	2.3
	Madura Island: Lighthouse	7 02 00	112 41 09				
	Soemenep flagstaff	7 02 30	113 53 45				
	Besuki: Lighthouse	7 43 25	113 41 10				
	Cape Sedano: NE. pt. of Java	7 49 00	114 26 53				
	Banjuwangi: Fort	8 12 30	114 22 55	10 00	3 45	7.8	2.6
	Bantenan: S. pt. of Java	8 47 00	114 25 13				
	Barung Island: S. pt	8 32 00	113 15 00				
	Kambangan Island: Lighthouse	7 46 30	109 02 12	8 33	2 21	5.2	1.8
	Cape Anjoe: Extreme	7 25 00	106 24 30				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Smaller Dutch East Indian Islands.	Karimon Djawa Island: Flagstaff	5 52 57	110 25 29				
	Rawean Island: Sangkapura flagstaff	5 51 18	112 39 10				
	Great Solombo Island: NW. pt	5 32 28	114 23 42				
	Arentes Island: S. pt	5 05 46	114 35 00				
	Bali Island: Buleleng lighthouse	8 05 30	115 03 48				
	Peak, 11,326 ft	8 21 00	115 28 00				
	Badong Bay, Kotta village	8 42 30	115 08 47	10 50	4 38	8.7	3.0
	Lombok Island: Peak, 12,379 ft	8 23 00	116 27 30				
	Ampenam light	8 34 15	116 04 09	7 50	1 37	5.8	2.0
	Sumbawa I.: Sumbawa village	8 32 00	117 20 33				
	Tambora Volcano, summit E. side of crater	8 12 30	117 57 00				
	Bima, flagstaff	8 27 00	118 43 55	0 00	6 12	5.7	2.0
	Postilion Islands: N. island	6 31 00	118 43 00				
	Maria Reigersbergen I.	7 30 00	117 56 00				
	Ardassier Islands: S. id	7 35 00	117 22 00				
	Brill Reef: Lighthouse	6 05 50	118 56 50				
	Hegadis Island	6 07 00	122 40 00				
	Token Bessi I.: Wangi-Wingi, NW. pt	5 15 00	123 32 00				
	Binongko, S. pt	6 17 00	123 59 00				
	Gunong Api: Volcano	6 43 00	126 43 30				
	Lucipari Islands: N. islet	5 28 30	127 30 00				
	Flores Island: Reo village	8 16 15	120 29 55				
	Ende village	8 50 55	121 38 40				
	Flores Head, extreme	8 04 45	122 52 00				
	Komba Island: Peak, S. part	7 48 00	123 31 00				
	Adenara Island: Summit, Mount Woka	8 20 30	123 15 00				
	Lombata Island: Mount Lamararap	8 33 00	123 22 00				
	Pantar Island: S. peak of saddle on S. pt.	8 34 00	124 06 00				
	Ombay Island: Dololo anchorage	8 12 00	124 23 00				
	Timor Island: Deli, customhouse	8 34 00	125 33 57	0 45	6 58	5.7	2.0
	Atapopa	9 00 00	124 52 00				
	Koupang, Fort Concordia	10 09 54	123 33 57	10 50	4 37	8.5	2.9
	Rotti Island: W. pt	10 46 00	122 52 00				
	Saru Island: Seba Bay, on NW. side	10 29 00	121 46 00				
	Sandalwood Island: Nangamessie	9 35 03	120 14 30	11 20	5 07	16.5	5.6
Molukka Islands.	Wetta Island: Ilwaki road	7 53 00	126 22 00				
	Roma Island: W. pt	7 38 00	127 19 00				
	Moa Island: Buffalo Peak, 4,100 ft	8 12 00	128 01 00				
	Sermata Island: NE. pt	8 14 00	129 00 00				
	Damma Island: Kulewatta Harbor, N. pt.	7 03 00	128 28 00				
	Nila Island: Center	6 44 00	129 29 00				
	Mano or Bird Island: NW. extremity	5 32 50	130 17 44				
	Timor Laut Island: Olilet, on E. coast	7 55 00	131 23 30				
	Vordate Island: S. pt	7 04 00	131 55 00				
	Mulu Island: N. pt	6 35 00	131 34 00				
	Aru Islands: S. island	7 05 00	134 31 00				
	N. pt	5 20 00	134 40 00				
	Great Ki Island: S. pt	5 56 00	132 54 00				
	Tello Islands: S. island, summit	5 20 00	131 58 00				
	Tehor Island: NE. pt	4 44 00	131 47 00				
	Matabella Islands: Kukur	4 33 00	131 50 00				
	Goram Islands: Goram Mosque	4 03 05	131 25 23				
	Banda Island: Mole	4 31 53	129 53 18	1 45	7 57	9.0	6.6
	Bouro Island, Kajeli: Fort Defense	3 22 48	127 06 18	1 20	7 32	4.2	3.1
	Ceram Island: Kawa	2 55 52	128 07 04				
	Amboina Island: Lighthouse	3 41 00	128 10 00	2 20	8 32	7.5	5.5
	Sula Islands, Taliabo Island: NW. pt	1 44 00	122 20 00				
	Mangola Island: E. pt	1 48 12	126 21 19				
	Besi Island: E. pt	2 28 00	126 01 00				
	Obi Major Island: W. pt	1 30 00	127 18 00				
	Popa Island: Outer Extremity Bay	1 11 21	129 55 48				
	Mysole Island: Efbe Harbor	2 04 00	130 12 00				

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Molukka Islands.	Gebey Island: NW. pt.	0 02 02	129 17 30	......	......	......	......
	Halmahera I., Cape Tabo: E. extreme	0 11 00	128 52 00	......	......	......	......
	(Gillolo I.) Cape Salawag: N. E. pt.	1 26 00	128 37 00	......	......	......	......
	Derrick Point: N. extreme	2 12 00	128 03 30	......	......	......	......
	Makkian or Makjan I.: Fort Reeburgh	0 24 00	127 21 00	......	......	......	......
	Ternate Island: Residency flagstaff	0 47 13	127 22 39	5 00	11 10	3.9	2.9
		Lat. S.					
	Batian Island: Church	0 38 03	127 28 21	......	......	......	......
		Lat. N.					
Borneo.	Tanjong Datu	2 05 15	109 39 07	......	......	......	......
	Sarawak River: Po Pt. light	1 43 50	110 30 30	4 00	10 12	9.0	3.9
	Sarawak: Fort	1 33 55	109 20 40	5 20	11 35	14.1	6.1
	Cape Sirik: Lighthouse	2 45 20	111 21 20	......	......	......	......
	Tanjong Barram	2 36 15	113 58 57	......	......	......	......
	Bruni River: Lighthouse	5 02 00	115 03 00	......	......	......	......
	Labuan I., Victoria Hbr.: Lighthouse	5 15 25	115 16 05	9 35	3 23	5.5	2.4
	Sandakan Harbor: Flagstaff	5 50 24	118 07 12	12 00	5 50	6.8	1 to 4
	Unsang: Anchorage	5 16 30	119 16 00	......	......	......	......
	Tanjong Mangkalihat E. pt. of Borneo	1 01 12	119 00 00	......	......	......	......
		Lat. S.					
	Pamaroong I.: E. pt. delta River Koetei	0 45 00	117 37 00	[7 45]	[1 33]	[7.0]	......
	Pulo Laut: S. pt. Koengit Islet	4 05 42	116 01 40	......	......	......	......
	Selatan Point: Extreme of Sita Pt	4 10 40	114 42 18	......	......	......	......
	Bandjermasin: Residency flagstaff	3 18 55	114 34 56	......	......	......	......
	Sampit Bay: Bandaran Pt	3 16 00	113 08 00	......	......	......	......
	Kottaringin Bay: Samadra I	2 54 00	111 24 00	......	......	......	......
	Succadana: Town	1 14 00	109 58 00	......	......	......	......
	Padang Tikar: Point	0 40 00	109 16 00	7 00	0 47	7.2	3.1
Celebes Island.	Port Laykan: SW. pt. of Celebes	5 36 00	119 26 00	......	......	......	......
	Makassar: Fort light	5 08 09	119 23 55	4 40	10 55	3.9	2.9
	Palos Bay: Village at head	0 57 00	119 47 30	......	......	......	......
		Lat. N.					
	Cape Rivers: NE. Cape, Slime Islet	1 20 00	120 43 30	......	......	......	......
	Gorontalo: Lighthouse	0 29 41	123 03 08	......	......	......	......
	Manado Bay: Lighthouse	1 31 00	124 50 00	6 00	12 15	4.3	3.1
	Bajuren Island: Summit	2 07 00	125 22 00	......	......	......	......
	Tagulanda Island: Peak	2 22 00	125 24 30	......	......	......	......
	Seao Island: Conical peak	2 44 00	125 26 00	......	......	......	......
	Sauguir Island: S. pt. Cape Palumbatu	3 21 00	125 39 00	......	......	......	......
	Taluat Island: Kabruang I., SE. pt	3 49 00	127 02 30	......	......	......	......
	Cape Flesko: Extreme	0 27 00	124 26 00	......	......	......	......
		Lat. S.					
	Cape Talabo: E. end	0 46 00	123 27 00	......	......	......	......
	Wowoni Island: N. pt	3 58 00	123 00 00	......	......	......	......
	Bouton Island: N. pt	4 23 30	123 04 00	......	......	......	......
	E. pt	5 15 00	123 16 00	......	......	......	......
	Fort	5 29 15	122 36 41	......	......	......	......
	Cape Lassa: Extreme	5 35 00	120 29 00	......	......	......	......
	Salayar Island: N. pt	5 47 00	120 30 00	......	......	......	......
	S. pt	6 26 00	120 28 30	......	......	......	......
		Lat. N.					
Philippine Is.	Balabac Island, Cape Melville: Lighthouse	7 49 25	117 00 00	......	......	......	......
	Palawan Island, Cape Buliluyan: S. extreme	8 20 25	117 09 35	......	......	......	......
	Victoria Peak, 5,680 ft.	9 22 30	118 17 30	......	......	......	......
	Port Royalist: Tide Pole Pt. Light	9 43 43	118 43 03	[11 30]	[5 20]	[6.5]	......
	Taytay Fort	10 50 00	119 31 10	......	......	......	......

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Philippine Islands.	Palawan Island, Port Barton: Bubon Pt.	10 29 19	119 05 36				
	Kabuli I.: Summit, N. extreme:	11 26 25	119 29 55				
	Cuyo Island: Obs. spot	10 51 26	121 00 25				
	Agutaya Islet: Summit of Mt. Aguade	11 09 09	120 56 26				
	Quiniluban Islet: Summit	11 25 47	120 45 38				
	Culion Island: Fort	11 53 53	120 00 48				
	Busuanga Island: Mt. Tundalara	12 02 09	120 12 56				
	Apo Islet: Summit	12 39 46	120 27 18				
	Caluya Island: Summit	11 54 28	121 30 24				
	Semerara Island: N. extremity	12 06 45	121 20 10				
	Mindoro Island: Mangarin Pt., SE. extremity	12 20 03	121 03 33				
	Sablayan Pt., Vantay	12 50 15	120 44 42				
	Monte Calavite	13 28 40	120 22 33				
	Escarceo Pt	13 31 35	120 59 17				
	Pt. Dumaly	13 06 05	121 29 20				
	Ylin Island	12 17 15	121 01 53				
	Lubang Island, Port Tulig	13 49 30	120 09 58				
	Luzon Island, Batangas: Ast. station	13 45 22	121 02 56				
	Balayan: Plaza Rizal	13 56 17	120 43 37	[11 07]	[4 50]	[4. 9]	
	Loro Peak: Summit, 3,985 feet	14 12 20	120 38 10				
	Caballo I.: Lighthouse	14 21 48	120 36 40				
	Corregidor Island: Lighthouse	14 22 27	120 33 48	[10 22]	[3 56]	[4. 4]	
	Cavite: Sangley Pt. light	14 29 57	120 54 43				
	Manila: Pasig lighthouse	14 35 49	120 57 19	10 44	[4 10]	[4. 6]	
	Manila: Cathedral	14 35 31	120 58 06				
	Subic: Town	14 52 36	120 13 52	[9 42]	[4 33]	[3. 8]	
	Capones Islet: Lighthouse	14 55 33	120 00 15				
	Iba: Ast. station	15 19 30	119 57 11				
	Port Masinloc: Bani Pt	15 34 48	119 54 16				
	Santa Cruz: Plaza	15 45 43	119 54 00				
	Sual: Army Hospital	16 04 06	120 06 01	[10 20]	[3 33]	[2. 4]	
	Silaqui Islet: Summit	16 27 15	119 56 10	[10 21]	[3 44]	[2. 3]	
	Port San Fernando: Main street	16 37 15	120 18 25	[9 40]	[3 29]	[2. 6]	
	Candon: Ast. station	17 11 43	120 26 14				
	Port Santiago: Remarkable tree S. of port	17 16 55	120 25 07				
	Vigan: Race track	17 33 56	120 22 51				
	Salomague Island: Port Salomague flagstaff	17 47 17	120 25 04				
	Currimao: Town	18 01 09	120 28 44				
	Cape Bojeador: Lighthouse	18 31 08	120 35 35				
	Mairaira Pt.: Semaphore	18 39 02	120 50 53				
	Aparri: Plaza	18 21 43	121 37 27	5 43	−0 02	3.2	1.9
	Port San Vicente: San Vicente Islet	18 28 32	122 04 14				
	Cape Engaño: Roña Islet	18 32 02	122 05 49				
	Camiguin I.: Summit	18 50 26	121 48 26	6 00	−0 12	5.0	2.7
	Fuga Island: W. summit	18 52 54	121 15 42				
	Dalupiri Island: Peak	19 03 03	121 11 28				
	Calayan Island: NE. pt	19 22 00	121 32 00				
	Babayan Claro Island: W. pt	19 30 00	121 52 00				
	Balingtang Islands	19 58 30	122 14 00				
	Batan Island: Mount Irada	20 28 30	122 01 20				
	Ibayat Island: Mount Santa Rosa	20 48 00	121 52 30				
	Yami Island: Islet off SW. part	21 04 56	121 58 24				
	Luzon Island, Port Dimasalasan: Entrance	17 20 17	122 19 20				

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Philippine Islands.	Luzon Island, Polillo I: Port Polillo	14 51 00	121 54 48				
	Tabaco: Church belfry	13 21 33	123 43 53	6 08	0 00	5.2	2.8
	Catanduanes Islands: N. islet	14 09 00	124 06 48				
	Catanduanes Islands: S. extreme	13 28 30	124 04 48				
	Point Calaan: S. extreme	12 31 20	124 04 18				
	Port Sorsogon, Tinacos Islet	12 52 20	123 49 22				
	Masbate Island, Palanog: Pier	12 22 10	123 35 58				
	Bugui Pt. lighthouse	12 36 00	123 14 36				
	Camasusu I.: Summit	12 10 03	123 12 47				
	Tintolo Point: Extreme	11 56 09	123 07 34				
	Burias Island: Busainga	13 07 40	123 02 45	[4 30]	[10 20]	[5.5]	
	Marinduque I.: Summit of Mount Catala	13 18 10	121 54 33				
	Maestro de Campo Island, Port Concepcion: Point Fernandez	12 54 03	121 43 08				
	Banton Island: Banton Mountain	12 56 56	122 04 48				
	Tablas Island: Tablas Head	12 38 42	122 08 38				
	Sanguilan Pt	12 33 44	121 58 32				
	Carabao Island: W. pt	12 03 15	121 53 53				
	Romblon Island: Sabang Pt. light	12 36 00	122 17 08				
	Summit over port	12 35 33	122 16 26				
	Sibuyan Island: Summit	12 24 55	122 33 23				
	Samar Island, Guiuan: Pier	11 01 30	125 43 14				
	Catbalogan: Fort	11 46 44	124 51 37				
	Maripipi Island: Summit	11 47 30	124 18 15				
	Leyte, Tacloban	11 15 08	124 59 56	6 53	1 25	1.5	1.1
	Ormoc: Ast. station	11 00 17	124 36 20				
	Palompon: Church	11 02 37	124 22 07				
	Maasin	10 07 39	124 50 15	11 47	4 50	2.8	2.0
	Bohol I., Lapiniu I.: Mount Basiao	10 03 22	124 32 35				
	Cebu Island, Cebu: Plaza	10 17 30	123 54 18				
	Siquijor Island, Port Canoan: S. pt. of entrance	9 15 17	123 34 26				
	Negros Island, Port Bunbonon; E. pt. of entrance	9 03 37	123 06 09				
	Dumaguete: Town	9 18 25	123 18 43				
	Volcano of Malaspina, 8,192 ft	10 24 35	123 07 05				
	Bacalod: Town	10 40 21	122 55 42				
	Guimaras I., Inampulugan I., SW. pt	10 26 38	122 40 20				
	Panay Island, Iloilo: Fort	10 41 27	122 34 26	11 06	5 22	4.2	1.9
	San José	10 44 08	121 54 27				
	Pan de Azucar	11 16 47	122 09 09				
	Batbatan Island: Summit	11 28 20	121 52 36				
	Pucio Point: Extreme	11 45 30	121 58 59				
	Port Batan: Village	11 35 40	122 28 50				
	Capiz: Town	11 35 06	122 45 03				
	Siargao Island, Port Sapao: Semaphore	10 11 26	126 02 53				
	Gibdo Island: Semaphore	9 53 00	125 31 17				
	Bucas Island: E. pt. of Port Sibanga	9 41 34	125 58 22				
	Mindanao Island: Surigao	9 47 53	125 28 30	[11 40]	[6 15]	[6.5]	
	Cape St. Augustin	6 14 30	125 47 48				
	Davao: Mole	7 01 22	125 34 35	6 00	−0 13	6.9	5.1
	Saranguni Islets: W. islet	5 22 30	125 13 48				
	Basianang Bay: N. pt. of Donauang I	6 28 50	123 57 37				
	Polloc: Small hill back of town	7 21 15	124 11 42				
	Santa Cruz Islands: SE. islet	6 52 15	122 04 00				
	Zamboanga: Fort	6 54 03	122 04 52	6 50	0 42	3.8	2.8

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APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Philippine Islands.	Mindanao Islands Sibuco Bay: Hill S. of beach	7 18 05	122 03 18				
	Port Sta. Maria: Fort	7 45 41	122 04 58				
	Dapitan: Village	8 40 15	123 23 13	[10 48]	[4 50]	[5. 1]	
	Misamis: Fort	8 08 29	123 50 44				
	Camiguin Island: Mount Camiguin	9 10 19	124 42 50				
	Sombrero Rock: Center	10 43 00	121 33 00				
	Piedra Blanca: Center	10 27 00	121 03 00				
	Cagayanes Islands: Rocky islet between two larger islands	9 35 30	121 23 30				
	San Miguel Isles: E. pt. of Manuk Manukan	7 43 00	118 27 00				
	Cagayan Jolo Island: Middle of W. coast	7 00 38	118 26 06				
	Omapui Island: NW. extreme	4 54 10	119 22 45				
	Sibutu Island: Hill on E. coast	4 49 30	119 48 00				
	Simonor Island: NW. pt	4 55 30	119 46 45				
	Bahaltolis Island: Sandakan Harbor	5 50 00	118 11 00				
	Bongao Island: S. pt	5 00 30	119 44 15				
	Keenapoussan Island: Center	5 13 00	120 40 45				
	Bubuan Island: Lagoon entrance	5 25 15	120 35 00				
	Cuad Basang Island: SW. pt	5 27 10	120 11 30				
	Siassi: Town, center of old fort	5 32 35	120 48 51	5 54	−0 18	8. 6	6. 4
	Bulipongpong Island: Center hill	5 41 30	120 49 45				
	Tapul Island: Center hill, 1,676 ft	5 44 30	120 55 00				
	Jolo Islands: Maimbun Anchorage, dry bank	5 54 45	121 00 40				
	Dalrymple Harbor, Tulyan Islet	6 02 30	121 18 20				
	Jolo lighthouse	6 03 30	120 59 52	[9 38]	[3 10]	[5. 0]	
	Doc Can Islet: W. extreme	5 52 30	119 55 55				
	Pangituran Island: SW. pt	6 15 15	120 29 30				
	Basilan Island: La Isabela	6 42 43	121 56 50				
Gulf of Siam.	Pulo Varella: Center	3 17 00	103 40 00				
	Pulo Brala: Center	4 53 00	103 38 00				
	Tringano River: N. pt	5 21 40	103 08 00	8 00	1 48	5. 8	2. 5
	Great Redang Harbor: Bukit Mara	5 44 21	103 01 45				
	Kelantan R.: Lighthouse	6 13 25	102 10 30				
	Tanjong Patani: NE. pt	6 57 01	101 17 39				
	Singora (Sungkla): SW. pt. of Koh Ngu	7 13 54	100 36 12	8 20	2 08	2. 8	1. 2
	Koh Krah Islet: SE. pt	8 24 47	100 45 27				
	Bangkok: Wat Cheng	13 44 32	100 29 29	8 00	2 00	7. 3	3. 1
	Cape Liant: Koh Chuen Lighthouse	12 31 00	100 57 30				
Cochin China.	Chentabun River: Entrance, Bar I	12 27 43	102 04 19	10 00	3 50	4. 5	2. 1
	Koh Chang: Obsy. I. on W. side	12 01 55	102 15 47				
	Koh Kong R.: S. pt. of entrance	11 33 00	102 57 14				
	Kusrovie Rock: Center	11 06 25	102 47 49				
	Koh Tang Rocks: Veer Islet	10 13 45	102 52 45				
	Panjang Island: West Pt	9 18 14	103 27 14				
	Obi Islands: Lighthouse	8 25 20	104 48 30				
	Saigon: Observatory	10 46 47	106 42 12	5 00	11 20	9. 8	4. 2
	Mitho: S. gate of citadel	10 21 16	106 20 38				
	Cape St. James: Lighthouse	10 19 51	107 04 55				
	Cape Padaran: Extreme	11 21 00	108 58 00				
	Cape Varella: Extreme	12 53 40	109 23 42				
	Quin Hon: Battery flagstaff	13 45 23	109 14 52				
	Canton Pulo: Lighthouse	15 23 34	109 05 35				
	Cham-Callao Islet: Watering place	15 57 10	108 32 47				
	Tourane Bay: Lighthouse	16 07 00	108 11 30				
	Hon-Mé: Summit	19 22 14	105 55 22				
	Nam-Dinh: Citadel tower	20 25 30	106 08 41				
	Hon Dau Island: Lighthouse	20 40 03	106 47 10	9 00	2 48	4. 3	2. 1
	Haifong: Observation pagoda	20 51 44	106 40 54				
	Haiduong: Citadel tower	20 56 29	106 17 56				
	Hanoi: Citadel tower	21 01 57	105 48 40				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
China Sea.	Condore Islands: Lighthouse	8 40 06	106 41 42				
	Safatu Island: Summit	9 58 23	109 06 00				
	Ceicer de Mer Island: SW. hill	10 32 36	108 56 27				
	Natuna Islands: Murundum I., SE. pt	2 02 55	109 06 10				
	Low I	3 00 00	107 48 00				
China.	Pakhoi: Customhouse flagstaff	21 29 00	109 06 00	5 00	11 12	14.0	6.6
	Hainan Island: Cape Bastion, extreme	18 09 00	109 35 00				
	Gaalong Bay, E. Brother	18 11 30	109 41 30				
	Lighthouse	20 01 15	110 16 10				
	Paracel Islands: Triton I	15 46 30	111 14 30				
	Observation bank	16 36 00	111 40 30				
	Lincoln I	16 40 07	112 43 32				
	Woody I	16 49 55	112 20 44				
	Pratas Island: NE. part	20 42 03	116 43 07				
	Ty-fung-kyoh Island: Center	21 22 30	111 10 30				
	Tien-pak Harbor: Pauk Pyah Islet	21 24 15	111 15 25	11 50	5 37	8.2	3.8
	Song-yui Point: Extreme	21 31 00	111 38 30				
	Hui-lang-san Harbor: Mamechow Islet	21 34 00	111 46 43				
	Mandarins Cap: Summet, 200 ft	21 28 00	112 21 30				
	Macao: Fort Guia light	22 11 40	113 34 00	9 50	3 38	6.3	3.0
	Fort San Francisco	22 11 24	113 33 25				
	Canton: Dutch Folly light	23 06 35	113 16 30	2 00	8 00	5.1	2.4
	Raleigh Rock: Center	22 02 00	113 47 00				
	Gap Rock: Lighthouse	21 48 50	113 56 20				
	Hongkong: Cathedral	22 16 52	114 09 31				
	Wellington Battery	22 16 23	114 10 02	9 20	2 52	4.4	2.0
	Lema Island: Lema Head	22 03 40	114 19 25				
	Nine-pin Rock: Center	22 15 45	114 22 07				
	Tuni-ang Island: Summit	22 27 06	114 36 45				
	Single Island: E. summit	22 24 06	114 39 12				
	Mendoza Island: Summit	22 30 42	114 50 00				
	Pank Piah Rock: Summit	22 32 54	115 01 00				
	Pedra Blanca Rock: Summit, 130 ft	22 18 30	115 06 54				
	Chino Bay: Obs. spot	22 48 14	115 47 56				
	Cupchi Point: Hill	22 48 07	116 04 26				
	Breaker Point: Lighthouse	22 56 24	116 29 44				
	Cape of Good Hope: Lighthouse	23 14 00	116 47 00				
	Swatow: British consulate	23 20 43	116 40 22	2 50	9 00	7.5	3.5
	Lamock Island: Lighthouse	23 15 43	117 17 04				
	Brothers Islets: SE. Islet	23 32 30	117 42 00				
	Tong-sang Harbor: Fall Peak	23 47 15	117 36 48	11 20	5 08	12.0	7.6
	Chapel Island: Lighthouse	24 09 49	118 13 30				
	Amoy: Taitan I. light	24 23 16	118 10 00	0 05	6 13	15.5	9.9
	Dodd Island: Lighthouse	24 25 44	118 30 11				
	Chinchin Harbor: Pisai Islet	24 49 13	118 41 00				
	Pyramid Point: Extreme	24 52 12	118 58 00				
	Ockseu Island: Lighthouse	24 59 36	119 27 07				
	Sorrel Rock: Summit	25 02 18	119 10 36				
	Lamyit Island: High Cone Peak	25 12 00	119 35 00				
	Hungwha Channel: Sentry I	25 16 30	119 45 00				
	Turnabout Island: Lighthouse	25 26 10	119 56 07				
	East Dog Island: Lighthouse	25 58 10	119 59 02				
	Min River: Pagoda, Losing I	25 59 00	119 27 16	0 30	7 00	19.3	12.2
	Temple Pt	26 08 26	119 37 35	9 45	3 33	19.0	12.0
	Alligator Island: Summit	26 09 29	120 24 06				
	Tung-yung Islands: Peak, N. end	26 22 37	120 29 40				
	Coney Island: Summit	26 30 00	120 10 00				
	Double Peak Island: Highest peak	26 36 06	120 11 12				
	Pih-seang Island: Town I	26 42 30	120 22 42				
	Dangerous Rock. Summit	26 51 25	120 32 33				
	Tae Islands: Summit	26 58 52	120 42 34				
	Nam-quan Harbor: Bate I	27 09 20	120 25 50	9 50	3 38	17.2	10.9
	Ping-fong Island: Summit	27 09 42	120 32 42				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
China.	Pih-quan Peak: Summit	27 19 18	120 27 14				
	Port Namki: E. horn	27 26 18	121 06 36				
	Pih-ki-shan Island: Summit	27 37 36	121 12 09				
	Pe-shan Islands: Summit, SW. end	28 05 07	121 30 04				
	Tung-chuh Island: Summit	28 43 45	121 55 21				
	Kweshan Islands: Patahecock	29 22 45	122 13 16				
	Nimrod Sound: Middle islet	29 34 20	121 43 15				
	Tong-ting Islet: Summit	29 51 53	122 35 24				
	Chin-hai: Citadel	29 57 08	121 43 06				
	Ning-po: Square I. light	29 59 21	121 45 22	1 00	7 12	8.8	4.6
	Chusan Islands: Ting-hai Harbor	30 04 30	122 03 47				
	Video Island: Summit	30 08 04	122 45 48				
	West Volcano Island: Lighthouse	30 20 50	121 51 25				
	Chapu: Battery	30 36 00	121 03 00				
	Gutzlaff Island: Lighthouse	30 48 37	122 10 12				
	Saddle Islands: N. Saddle light	30 51 41	122 40 17				
	West Barren Island: Summit	30 44 07	123 08 27				
	Shanghai: Eng. consulate flagstaff	31 14 41	121 28 55				
	Woosung: Lighthouse	31 23 18	121 29 36	0 12	8 06	9.1	4.8
	Shaweishan Island: Lighthouse	31 25 27	122 14 12				
	Wang-kia-tia Bay: Langwang temple	35 39 00	119 51 30				
	Kiaochow Bay: Yunui San light	36 02 50	120 17 30	4 50	11 03	11.4	6.0
	Staunton Island: Landing place, N. side	36 45 29	122 16 48				
	Shantung Promontory: Lighthouse	37 24 00	122 42 00	4 00	10 12	6.8	5.0
	Weihaiwei: Light, S. side harbor	37 27 41	122 15 05	9 20	3 08	9.0	6.6
	Chifoo: Lighthouse	37 34 10	121 31 09	10 25	4 13	8.1	6.0
	Fort flagstaff	37 32 51	121 21 27				
	Miautao Island: Peak of N. Island	38 23 37	120 55 00				
	Pei Ho: S. Taku Fort, S. Cavalier	38 58 16	117 42 48				
	Tientsin: Shore opp. NE. angle of wall	39 09 00	117 11 44	6 50	1 00	4.5	3.3
	Shaluitien Island: Lighthouse	38 56 00	118 31 00				
	Newchwang: Lightship	40 35 00	122 00 00	4 30	10 50	11.7	8.7
	Hulu-shan Bay: N. side	39 30 46	121 18 03				
	Port Adams: Entry	39 16 00	121 35 59				
	Liao-ti-shan Promontory: SW. pt. light	38 43 17	121 08 26				
	Ryojun Ko (P. Arthur): Obs. spot	38 47 50	121 15 54	10 05	3 53	7.5	5.5
	Dairen Wan: Isthmus on S. Sanshan I	38 52 38	121 51 59				
	Round Island: Summit	38 40 00	122 11 30				
	Thornton Haven, Hai-yun-tan Island: Beach opposite Temple Point	39 04 00	123 10 34				
	Pescadores Islands: Fisher I. light	23 32 53	119 28 05				
	Second pt. on N. side Makung Harbor	23 32 54	119 30 12				
Taiwan (Formosa).	South Cape: Lighthouse	21 55 00	120 51 00				
	Takau: Saracen Head	22 36 14	120 15 54	9 45	3 32	4.0	1.7
	Port Heongsan	24 46 00	120 55 00				
	Tamsui Harbor: White Fort	25 10 24	121 25 00	10 00	3 47	8.0	3.4
	Kiirun Ko (Kelung Hbr.): Lighthouse	25 09 12	121 44 28	10 15	4 03	3.0	1.3
	Soo (Sauo) Bay: Beach near village	24 35 28	121 49 20	6 00	12 13	5.8	2.5
	Botel Tobago Sima: S. extreme	22 01 40	121 39 45				
S. W. Islands of Japan.	Sakishima Gunto, Kumi I.: N. beach	24 26 00	122 56 00				
	(Meiaco Sima Is.) Broughton Bay: Landing place	24 21 30	124 17 40				
	Port Haddington: Hamilton pt	24 25 00	124 06 40				
	Tai-pin-san: Hirara, Karimata Anch	24 48 18	125 17 57	7 27	1 14	4.9	2.1
	Raleigh Rock: Summit, 270 ft	25 55 00	124 35 00				
	Ti-ao-usu Island: Summit, 600 ft	25 58 30	123 40 00				
	Hoa-pin-su Island: N. face	25 47 07	123 30 31				

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
S. W. Isls. of Japan.	Nansei Shoto, Great Nansei: Nafa-Kiang.	26 12 25	127 40 10	6 30	0 15	5.8	2.5
	Yori-sima, 413 ft	27 02 00	128 25 24				
	Yerabu-sima peak, 687 ft	27 21 00	128 33 10				
	Kakirouma: Summit, 2,207 ft	27 44 00	128 59 00				
	Iwo-sima: Volcano, 541 ft	27 53 00	128 14 30				
	Oho-sima: N. extreme	28 31 40	129 42 30				
	Kikai-jima: Summit, 867 ft	28 18 00	129 59 00				
Tokara Is.	Kusakaki Jima: Ingersoll Rocks, 530 ft	30 51 00	129 28 00				
	Kuro Sima: 2,160 ft	30 50 00	129 55 30				
	Iwo Shima: Peak, 2,469 ft	30 47 00	130 18 00				
	Yakuno Shima: Mount Matomi, 6,252 ft	30 17 00	130 32 00				
	Firase Rocks: Highest, 92 ft	30 05 00	130 03 00				
	Kuchino Shima: Summit, 2,230 ft	29 59 00	129 56 00				
	Guaja Shima: Summit, 1,687 ft	29 54 00	129 33 00				
	Naka no Shima: Peak, 3,400 ft	29 52 00	129 52 30				
	Suwanose Jima: Volcano, 2,706 ft	29 38 00	129 42 00				
	Tokara Jima: Summit, 860 ft	29 08 00	129 13 30				
	Yoko Shima: Summit, 1,700 ft	28 47 30	129 01 30				
Chosen (Korea).	Choda Island: S. pt	38 27 00	124 34 40				
	Sir James Hall Islands: N. island	37 58 00	124 34 30				
	Chemulpo: So Wolmi	37 27 40	126 36 27	4 19	10 31	28.8	11.6
	Marjoribanks Harbor: Manzoc Islet	36 26 45	126 28 00				
	Tas de foin Islet: Center	36 24 30	126 24 00				
	Guerin Island: Summit, 969 ft	36 07 00	126 01 09				
	Kokoun-tan Islands: Camp Islet	35 48 08	126 31 00				
	Barren Island: Center, 600 ft	35 21 00	125 58 00				
	Sea Rock: Center, 160 ft	34 42 00	126 19 45				
	Modeste Island: N. peak, 1,228 ft	34 42 30	125 16 00				
	Ross Island: Peak, 1,920 ft	34 06 00	125 07 00				
	Kuper Harbor: NE. extreme of Josling I	34 17 20	126 35 28				
	Port Hamilton: W. pt. of Obs. Island	34 01 23	127 18 34	9 05	2 52	10.5	4.2
	Bate Islands: Summit Thornton Islet	33 57 00	126 18 00				
	Montravel Island: Center, 1,041 feet	33 59 00	126 55 00				
	Quelpart Island: Beaufort I., middle of W. side	33 29 40	126 58 25				
	Observation Island: Point of W. arm	34 39 00	128 14 00				
	Sentinel Island: Summit, 400 feet	34 33 00	128 40 00				
	Broughton Head: Extreme	34 48 00	128 44 00				
	Tsau-ling-hai Harbor: Lighthouse	35 07 15	129 02 10	7 35	1 23	7.0	3.0
	Cape Clonard: Extreme	36 05 45	129 33 30				
	Ping-hai Harbor	36 36 00	129 20 00				
	Liancourt Rocks: Summit, 410 ft	37 09 30	131 55 00				
	Matu Sima: Peak, 4,000 ft	37 30 00	130 53 00				
	Port Lazaref: S. 1½ miles from the S. end of Bontenef I	39 19 12	127 32 48				
Japan.	Tsu Sima: Observation rock	34 18 55	129 13 06	8 56	2 44	6.7	2.4
	Iki Sima: Summit, S. end of island	33 44 30	129 42 30				
	Oro No Sima: Summit, 277 ft	33 52 10	130 02 00				
	Kosime No Osima: Summit Wilson I	33 53 50	130 25 20				
	Yeboshi Sima: Lighthouse	33 41 30	129 58 50				
	Yobuko Harbor: Bluff opposite Nicoya	33 32 30	129 52 43	9 23	3 10	6.4	2.5
	Hirado No Seto: Taske light	33 23 31	129 33 21				
	Goto Island: Ose Saki light	32 36 45	128 36 10				
	Pallas Rocks: S. rock	32 13 12	128 04 39				
	Meiaco Sima: Ears Peak	32 03 00	128 25 00				
	Nagasaki: U. S. Transit Venus Station	32 43 21	129 52 25	7 54	1 41	8.4	3.5
	Nezumi Jima: Obs. spot	32 43 15	129 49 55	8 14		11.2	7.2
	Kuchinotsu: Lighthouse	32 36 05	130 13 40				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Japan.	Kagoshima: Breakwater light	31 35 39	130 33 49	6 40	1 00	10.5	4.4
	Tsukarase Rocks: Summit, 96 ft	31 20 00	129 46 20				
	Uji Shima: High Peak, 1,097 ft	31 12 00	129 29 00				
	Yamagawa Harbor: Spit N. of town	31 12 43	130 37 00	7 20	1 08	9.5	3.9
	Satano Misaki: Lighthouse	30 59 30	130 39 30				
	Shimonoseki Strait: Meji Zaki, extreme	33 57 46	130 57 50				
	Rokuren Island: Lighthouse	33 58 53	130 52 07	8 30	2 20	6.7	2.4
	Shirasu Reef: Lighthouse	33 59 11	130 47 36				
	Susaki: SW. battery	33 23 19	133 17 00	5 55	12 08	5.0	2.0
	Tomo Roads: Tamatsu Sima	34 22 37	133 23 23	11 16	5 04	10.2	4.5
	Port Okayama: Take Sima temple	34 35 58	133 59 24				
	Wusimado Pt.: Wusimado Peak, 548 ft	34 37 27	134 09 21				
	Akashi-no-seto: Maico Fort	34 38 05	135 01 51				
	Hiogo: Wada Misaki light	34 39 20	135 10 56				
	Kobe: Lighthouse	34 41 18	135 11 34				
	Osaka: Fort Temposan light	34 39 45	135 26 00	7 30	1 25	4.7	2.0
	Sakai: Pier-head light	34 35 12	135 27 44				
	Osaki Bay: Tree Islet, S. pt	34 07 42	135 08 19				
	Yura No Uchi: Pier	33 57 34	135 07 21				
	Tanabe Bay: Fossil pt	33 41 14	135 23 04				
	Oō-sima Hbr.: Kashinosaki light, E. pt	33 28 15	135 51 59				
	Uragami Harbor: Village pt	33 33 37	135 54 25				
	Owashi Bay: Hikimoto	34 06 10	136 14 35				
	Mura Harbor: Osima Islet	34 13 52	136 48 51	6 23	0 10	4.7	2.0
	Matoya Harbor: Anori-saki light	34 21 57	136 54 09	5 52	12 04	4.3	1.7
	Omoi Saki: Lighthouse	34 35 52	138 13 49				
	Shimizu Bay: Mound on pt	35 00 51	138 31 19	5 52	12 04	3.9	1.6
	Mikomoto Island: Light house	34 34 25	138 56 30				
	Simoda Harbor: Center I	34 39 49	138 57 30				
	Yokosuka Harbor: Eyi Yama pt	35 17 30	139 39 43				
	Yokohama: Time-ball station	35 26 41	139 39 00	5 25	11 30	4.9	1.9
	Tokio: University Observatory	35 39 18	139 44 30				
	No Sima Saki: Lighthouse	34 54 17	139 53 24	5 04	11 17	3.7	1.4
	Vries Island (O Sima) Volcano: Summit, 2,512 ft	34 43 30	139 23 00				
	Kozu Shima Volcano: Summit, 2,000 ft	34 13 15	139 08 00				
	Mikake Jima: Summit, 2,690 ft	34 05 00	139 31 00				
	Redfield Rocks: S. rock	33 56 50	138 48 15				
	Mikura Jima: Summit	33 52 00	139 34 00				
	Broughton Rock: Summit, 60 ft	33 39 00	139 17 45				
	Fatsizio Island: Observation spot	33 04 24	139 50 24				
	Aoga Shima: Center	32 29 00	139 43 31				
	Bayonnaise Island: Summit, 26 ft	32 00 40	140 00 00				
	Smith Island: Summit, 250 ft	31 27 00	140 02 00				
	Ponafidin Island: Summit, 1,328 ft	30 28 26	140 14 02				
	Lots Wife Rock: Summit, 300 ft	29 46 28	140 19 40				
	Inaboye Saki: Lighthouse	35 42 13	140 52 22				
	Kinkwosan Island: Lighthouse	38 16 57	141 35 33				
	Kamaishi Harbor: SE. end of village	39 16 30	141 52 50				
	Yamada Harbor: Ko Sima, 90 ft	39 27 17	141 59 00	4 30	10 45	3.4	1.3
	Siriya Saki: Lighthouse	41 25 58	141 27 32				
	Toriwi Saki: Center of Low Islet off	41 33 34	140 56 36				
	Aomori: Lighthouse	40 50 00	140 44 40				
	Tatsupi Saki: N. side	41 16 17	140 22 37				
	Bittern Rocks: SW. rock	40 31 00	139 31 00				
	Tobi Shima: Takamori Yama	39 12 02	139 32 58				
	Awa Sima: NE. extreme	38 29 23	139 15 31				
	Sado Island: Ya Saki	38 19 55	138 27 09				
	Fushiki Harbor: Lighthouse	36 47 47	137 03 15				
	Cape Rokugo: Extreme	37 31 45	137 19 00				
	Niigata: Buddhist temple	37 55 14	139 03 01				
	Mana Sima: Summit, 200 ft	37 35 00	136 54 00				
	Manao Harbor: Sorenjo Pt	37 02 37	136 58 24				
	Tsuruga: Town	35 40 24	136 01 22	2 30	8 42	0.6	0.4

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Japan.	Oki Islands: N. pt	36 30 00	133 23 00				
	Taka Yama (Cape Louisa): Extreme	34 40 00	131 36 00	11 41	5 28	1.1	0.5
	Ai Sima: Summit, 300 ft	34 32 00	131 18 00				
	Mino Sima: Summit, 492 ft	34 48 00	131 09 00				
	Kado Sima: Tsuno Shima light	34 21 12	130 50 29				
	Hakodate: Lightship	41 47 36	140 41 49	3 40	10 00	3.0	1.2
	Endermo Harbor: Bluff on E. side	42 19 54	140 59 33	3 32	9 45	3.5	1.5
	Okishi Bay: Lighthouse	42 56 52	144 52 38	3 41	9 53	3.0	1.4
	Noshiaf Saki: Lighthouse	43 22 56	145 49 10	3 48	10 00	3.1	1.4
	Nemuro: Benten Sima light	43 20 22	145 34 40	3 33	9 46	2.1	0.5
	Notsuke Anchorage: Village	43 33 11	145 18 00	4 50	11 05	3.7	1.8
	Noshiaf Misaki: Lighthouse	45 26 30	141 38 40				
	Risiri Islet: Peak, 5,713 ft	45 11 00	141 19 00				
Kuril Islands.	Kunashir Island: St. Anthonys Peak	44 20 00	146 15 00				
	Iturup Island: NE. pt	45 38 30	149 14 00				
	Urup Island: Cape Vanderlind	45 37 00	149 34 00				
	Broughton Island: Summit	46 42 30	150 28 30				
	Simusir Island: Prevost Peak	47 02 50	151 52 50				
	Ketoy Island: S. pt	47 17 30	152 24 00				
	Matana Island: Peak	48 06 00	153 12 30				
	Shiash-Kotan Island: Center	48 52 00	154 08 00				
	Kharim-Kotan Island: Peak	49 08 00	154 39 00				
	Oune-Kotan Island: SW. pt	49 19 00	154 44 00				
	Moukon rushi Island: Center	49 51 00	154 32 00				
	Porc musir Island: Fool's Peak	50 15 36	156 15 20				
	Soumshu Island: Center	50 46 00	156 26 00				
	Karafuto (S. Sakhalin):						
	C. Nortoro (Nishi Notoro Misaki) Light	45 53 10	142 04 51				
	C. Shiretoko (Nata Shiretoko Misaki)	46 01 20	143 26 30				
Siberia.	Sakhalin I., Cape Elizabeth: N. pt	54 24 30	142 46 30	11 20	5 08	4.2	1.7
	Wawoda Rock: Summit, 12 ft	42 14 30	137 17 00				
	Expedition Bay: Lighthouse	42 38 05	130 48 45				
	Port Novogorod: Lighthouse	42 33 40	131 10 00				
	Vladivostok: Cape Goldobin light	43 05 13	131 52 46	2 45	9 00	1.9	0.8
	Cape Povorotnyi: Lighthouse	42 41 00	133 02 00				
	Port Olga: Lighthouse	43 22 00	135 15 00				
	St. Vladimir Bay: Orekhera Pt	43 53 40	135 27 19				
	Shelter Bay	44 30 00	136 02 00				
	Sybillo Bay	44 43 45	136 22 30				
	Pique Bay	44 46 15	136 27 15				
	Bullock Bay	45 05 00	136 44 00				
	Luke Point: Extreme	45 19 30	137 10 15				
	Cape Disappointment: Extreme	45 41 30	137 38 15				
	Cape Suffren: Extreme	47 20 00	138 58 00				
	Cape St. Nikolaia: Lighthouse	48 59 30	140 23 40	9 50	3 40	2.7	1.1
	De Kastri: Lighthouse	51 28 00	140 48 00	10 45	4 40	6.3	2.6
	Nikolaevsk: Cathedral	53 08 05	140 42 58				
	Great Shantar Island: N. pt	55 11 00	137 40 00				
	Port Aian: Cape Vneshni	56 25 28	138 25 50	0 10	7 30	8.4	3.4
	St. Jona Island: Summit, 1,200 ft	56 22 30	143 15 45				
	Okhotsk: Battery	59 19 45	143 07 14				
	Cape Lopatka: Extreme	51 02 00	156 46 00	3 55	10 08	4.6	1.9
	Petropavlovsk: Rakof light	52 52 37	158 46 42	3 30	9 45	5.1	2.1
	Cape Shipunski: Extreme	53 04 30	160 04 00				
	Bering Island: Cape Khitroff	54 56 00	166 43 00				
	Mednoi, or Copper Island: SE. extreme	54 32 24	168 09 00				
	Cape Kamchatka: Extreme	56 10 00	163 24 00				
	Karajinski Island: S. pt	58 26 00	163 34 00				
	Cape Oliutorski: Extreme, 2,480 ft	59 55 00	170 22 00	6 00	12 15	4.5	1.8
	Cape Navarin: Extreme, 2,512 ft	62 14 30	179 04 30				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

EAST COAST OF ASIA—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Siberia.	St. Matthew Island: Cape Upright, SE. pt.	60 18 00	172 04 00	......	......	......	....
	St. Lawrence Island: N. pt.	63 12 00	159 50 00	......	......	......	....
	Cape Tchoukotskio: Extreme	64 16 00	173 10 00	......	......	......	....
	Port Providence: Emma Harbor	64 25 55	173 07 15	......	......	......	....
	Cape Indian: Extreme	64 24 30	172 12 30	......	......	......	....
	Arakam Island: Cape Kiguinin	64 46 00	172 07 00	......	......	......	....
			Long. E.				
	Anadir River: Mouth	64 50 00	178 40 00	......	......	......	....
			Long. W.				
	Cape Bering: Extreme	65 00 30	175 54 00	......	......	......	....
	East Cape: Extreme	66 02 00	169 32 30	......	......	......	....

ISLANDS OF THE PACIFIC.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
	Malpelo Island: Summit, 1,200 ft.	4 03 00	81 36 00	......	......	......	....
	Cocos Island: Head of Chatham Bay	5 32 57	86 59 17	......	......	......	....
Galapagos Islands.	Redondo Rock: Summit, 85 ft.	0 13 30	91 03 00	......	......	......	....
	Towers Island: W. cliff	0 20 00	89 58 43	......	......	......	....
	Bindloe Island: S. summit	0 18 50	90 30 08	......	......	......	....
	Abingdon Island: Summit, 1,950 ft.	0 34 25	90 44 23	......	......	......	....
	Wenman Island: Summit, 550 ft.	1 22 55	91 49 43	......	......	......	....
	Albemarle Island: Iguana Cove	0 59 00	91 29 12	2 00	8 13	6.2	3.1
	Marlborough Island: Cape Hammond	0 31 00	91 36 00	......	......	......	....
	James Island: Sugarloaf, 1,200 ft.	0 15 20	90 52 53	2 45	8 58	5.2	2.6
	Jervis Island: Summit	0 25 00	90 43 30	......	......	......	....
	Duncan Island: Center hill	0 36 30	90 41 00	......	......	......	....
	Indefatigable Island: NW. bay	0 33 25	90 33 58	2 00	8 13	6.2	3.1
	Barrington Island: W. summit, 900 ft.	0 50 30	90 06 13	......	......	......	....
	Charles Island: Summit, 1,780 ft.	1 19 00	90 28 13	2 10	8 23	6.0	3.0
	Fatu Huku or Hood Island: E. summit, 640 ft.	1 25 00	89 40 08	......	......	......	....
	Chatham Island: Mount Pitt, 800 ft.	0 44 15	89 16 58	2 20	8 33	6.5	3.3
	Christmas Island: N. pt. of Cook Islet	1 57 17	157 27 45	4 25	10 38	2.4	1.4
	Fanning Island: Flagstaff, entrance to English Hbr.	3 51 26	159 21 50	6 00	12 15	2.4	1.4
	Washington Island	4 41 10	160 24 30	......	......	......	....
	Palmyra Island	5 52 15	162 05 00	5 25	11 40	1.5	0.9
	Baker Islet: Center	0 13 30	176 32 39	......	......	......	....
	Howland Islands: Center island	0 49 00	176 43 09	7 10	1 00	6.2	3.6
		Lat. S.	Long. E.				
Gilbert Islands.	Arorai or Hurds Island: S. pt.	2 40 54	177 01 13	......	......	......	....
	Tamana Island: Center	2 35 00	176 07 00	......	......	......	....
	Onoatoa Island: Center	1 50 00	175 39 00	......	......	......	....
	Taputeuea or Drummond Island: SE. pt.	1 29 14	175 12 20	......	......	......	....
	Nukunau or Byron Island: SE. pt.	1 23 42	176 31 33	......	......	......	....
	Peru or Francis Island: NW. pt.	1 17 14	175 57 09	......	......	......	....
	Nonuti or Sydenham Island	0 36 00	174 24 00	......	......	......	....
		Lat. N.					
	Aranuka or Henderville Island: W. pt. of W. island	0 11 10	173 32 40	......	......	......	....
	Apamama or Hoppers Island: Entrance islet	0 20 54	173 51 14	4 30	10 45	4.7	2.7
	Maiana Island: S. pt.	0 51 30	173 03 30	......	......	......	....
	Tarawa Island: NE. pt.	1 38 45	173 03 00	......	......	......	....
	Apaiang Island: S. pt.	1 44 15	173 07 00	4 45	11 00	4.7	2.7
	Maraki Island: N. pt.	2 03 00	173 25 30	......	......	......	....
	Taritari Island: S. pt.	3 01 30	172 45 40	......	......	......	....

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE PACIFIC—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Marshall Islands.	Ebon Atoll: Rube Pt	4 35 25	168 41 31	4 45	11 00	4.7	2.7
	Jaluit or Bonham Islands: Jarbor Pier	5 55 07	169 39 31				
	Burrh Island: Port Rhin, N. pt. of entrance	6 14 00	171 46 00	5 00	11 15	5.0	2.8
	Majuro or Arrowsmith Islands: Anchorage Djarrit I	7 05 30	171 24 30				
	Arno Atoll: NE. pt	7 09 17	171 55 51				
	Odia Islands: S. islet	7 15 00	168 46 00				
	Namu Island: S. pt	8 14 00	168 03 00				
	Jabwat Island: Center	8 27 00	168 26 00				
	Aurh or Ibbetson Island: NE. end, anchorage	8 19 00	171 09 00				
	Maloclab Islands: NW. end Karen Islet	8 54 21	170 49 00				
	Wotje or Romanzov Islands: Christmas Harbor	9 28 09	170 16 05				
	Litkieh Island: NW. pt	10 03 40	169 01 57				
	Ailuk Islands: Capenfur Islet	10 17 25	169 59 20	4 50	11 00	6.2	3.6
	Bigar Islet: Center	11 48 00	170 07 00				
	Kongelab or Pescadores Islands: Center of group	11 19 21	167 24 57				
	Rongerik or Radakala Islands: Observation spot	11 24 00	167 35 00				
	Ailinginae Island: Easternmost Islet	11 07 00	166 35 00				
	Bikini or Eschholtz Islands: W. extreme	11 40 00	166 24 25				
	Wottho or Schanz Island: Center	10 05 00	166 04 00				
	Eniwetok Islands: North or Engibi I	11 40 00	162 15 00				
	Ujelang or Providence Island: Center of atoll	9 39 00	161 08 30				
	Greenwich Island: Northern islet	1 04 00	154 47 55				
Caroline Islands.	Matelotas group: Easternmost of the S. islands	8 18 30	137 33 30				
	Yap Island: Light in Tomil Bay	9 29 00	138 04 00	7 15	1 00	3.4	1.9
	Eau Island: Center	9 52 30	139 42 00				
	Uluthi or Mackenzie Islands: Mogmog Islet	10 06 00	139 46 00				
	Feys or Tromelin Island: E. extreme	9 46 00	140 35 00				
	Sorol or Philip Island: Center	8 06 00	140 52 00				
	Eauripik or Kama Islands: E. islet	6 40 00	143 11 00				
	Oleai group: Raur Islet, N. pt	7 21 45	143 57 30				
	Ifalik or Wilson Islets: N. end	7 15 00	144 31 00				
	Faraulep Island: S. end	8 35 00	144 36 00				
	W. Faiu Islet: Center	8 03 00	146 50 00				
	Olimarao Islet: Center	7 43 30	145 55 45				
	Toass Island: Center	7 29 30	146 24 30				
	Satawal Island: Center	7 22 00	147 06 48				
	Coquille or Pikelot Island: Center	8 09 00	147 42 00				
	Suk or Polusuk Island: S. end	6 40 00	149 21 00				
	Los Martires: Ollap Islet, N. pt	7 38 00	149 27 30				
	Namonuito Islands: Magur Islet	8 59 45	150 14 30				
	Hall Island: Namuine Islet	8 25 30	151 49 15				
	Hogolu (Hogulu) Group: N. end of Tsis Islet	7 18 30	151 56 30				
	Namoluk Islands: NW. islet	5 55 00	153 13 30				
	Mortlock Islands: Lukanor, Port Chamisso	5 29 18	153 58 00				
	Nukuor or Monteverde Islands: E. pt	3 51 00	155 00 54				
	Oraluk or Bordelaise Island: Center	7 39 00	155 05 00				
	Ngatik or Valientes Islands: E. extreme	5 48 00	157 31 30				
	Ponapi Island: Ponapi Harbor	7 00 35	158 17 35	4 00	10 15	4.3	2.4
	Mokil or Duperrey Islands: Aoura, NE. pt	6 41 45	159 50 00				
	Pingelasp or MacAskill Islands: E. end of island	6 14 00	160 38 43				
	Ualan or Strong Island: Chabrol Harbor	5 20 06	163 00 45	6 00	12 15	3.5	2.0

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE PACIFIC—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int.		Range.	
				H. W.	L. W.	Spg	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Pelew Islands.	Angaur Island: SW. pt	6 53 55	134 05 24				
	Pililu Island: S. pt	7 02 00	133 18 03				
	Earakong or Akamokan Islands: Center	7 08 00	134 27 00				
	Korro Islands: Korror Harbor, Malakal pier	7 19 00	134 32 30				
	Baubeltaub Island: Cape Artingal	7 40 30	134 39 30				
	Kyangle Islets: Center of largest	8 08 00	134 17 00				
	Warren Hastings Island: Center	4 20 00	132 21 00				
	Nevil or Lord North Island: Center	3 02 00	131 11 00				
	Sonserol Island: Approx	5 20 00	132 16 00				
Marianas (Ladrone Is.).	Guam: Fort Sta. Cruz, Harbor of Apra	13 26 22	144 39 42	7 20	1 20	2.6	1.5
	Rota Island: Summit	14 07 30	145 13 04				
	Tinian Island: Sunharon village	14 59 22	145 36 20				
	Saipan Island: Magicienne Bay, landing	15 08 30	145 43 55				
	Tanapag Hbr., Garapag	15 17 10	145 42 50	7 00	0 50	2.0	1.1
	Anataxan Island: Center	16 20 00	145 39 00				
	Sariguan Island: Center	16 41 00	145 47 00				
	Guguan Island: Center	17 17 00	145 57 00				
	Alamaguan Island: Center	17 36 00	145 55 00				
	Pagan Island: SW. pt	18 04 00	145 52 00				
	Agrigan Island: SE. pt	18 46 20	145 41 45				
	Asuncion Island: Crater, 2,600 ft	19 45 00	145 30 00				
	Urracas Islands: Largest islet	20 00 00	145 21 00				
	Farralon de Pajaros: S. end	20 32 54	144 54 00				
	Wake Island: Obs. spot	19 15 00	166 31 30				
	Gaspar Rico Reef: N. clump of rocks	14 41 00	168 54 28				
			Long. W.				
	Johnston or Cornwallis Islands: Flagstaff on W. island	16 44 48	169 32 24				
	Clipperton Island: Center	10 17 00	109 13 00				
Hawaiian Islands.	Hawaii Island: Hilo, Kanaha Pt. light	19 46 14	155 05 31	3 09	9 06	2.3	1.3
	Kawaihae light	20 03 00	155 48 00				
	Kealakeakua Bay light	19 28 00	155 55 00	2 20	8 10	1.6	0.9
	Kailua, stone church	19 38 26	156 00 15				
	Kahoolawe Island: Summit	20 33 39	156 35 04				
	Maui Island: Kanahena Pt. light	20 36 00	156 26 00				
	Lahaina light	20 52 00	156 35 00	3 32	9 58	2.2	1.2
	Molokai Island: Lighthouse	21 06 17	157 18 32	2 38	8 56	2.1	1.1
	Oahu Island: E. pt. Makapuu station	21 18 16	157 39 07				
	Diamond Head	21 15 08	157 48 44				
	Honolulu, Tr. of V. Obs	21 17 57	157 51 34				
	Honolulu, Reef light	21 17 55	157 51 54	3 46	9 59	1.5	0.8
	Kauai Island: Hanalei, Black Head	22 12 51	159 30 47				
	Waimea, stone church	21 57 17	159 40 08	4 00	10 20	2.0	1.1
	Bird Island: Center	23 05 50	161 58 17				
	Necker Island: Center	23 35 18	164 40 47				
	French Frigate Shoal: Islet (120 ft.)	23 46 00	166 17 57				
	Gardiner Island: Center	25 00 40	168 00 52				
	Maro Reef: NW. pt	25 31 00	170 39 20				
	Laysan Island: Lighthouse	25 48 00	171 44 00				
	Lisiansky Island: Lighthouse	26 00 00	173 57 00				
	Pearl and Hermes Reef: NE. extreme	27 56 30	175 46 00				
	Midway Islands: Lighthouse, Sand I	28 13 15	177 21 30	3 30	9 45	1.1	0.6
	Ocean Island: Sand Islet	28 24 45	178 27 45				
			Long. E.				
	Marcus Island: Center	24 14 00	154 00 00				

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE PACIFIC—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Ogasawara Is. (Bonin Is.), Parrys Group: N. rock	27 45 00	142 06 53	......	......	......	......
	Kater Island: N. rock	27 31 00	142 11 53	......	......	......	......
	Peel Island: Port Lloyd, observatory	27 05 37	142 11 23	6 10	0 00	2.4	1.4
	Volcano Is., San Alessandro Is. Sakakiga Mine	25 25 31	141 16 49	......	......	......	......
	Sulphur Island: Obs. Spot	24 47 40	141 18 16	......	......	......	......
	San Augustine Island: Center	24 14 00	141 20 00	......	......	......	......
	Rosario Island: Center, 148 ft	27 15 32	140 50 28	......	......	......	......
	Douglass Rocks: Center	20 30 00	136 10 00	......	......	......	......
	Borodino Islands: Center of N. island	25 59 38	131 19 30	......	......	......	......
	Center of S. island	25 52 45	131 12 17	......	......	......	......
	Rasa Island: Center	24 27 00	131 01 50	......	......	......	......
		Lat. S.	Long. W.				
Marquesas Islands.	Fatu Hiva Island: S. pt	10 32 00	138 39 20	......	......	......	......
	Motane Island: SSE. pt	10 01 40	138 48 30	......	......	......	......
	Tahuata Island: Port Resolution, watering place	9 56 00	139 09 00	2 30	8 45	3.1	1.9
	Hiva-Oa Island: C. Balguerie	9 45 00	138 47 40	......	......	......	......
	Fatu Huku Island: Center	9 27 30	138 55 10	......	......	......	......
	Roa Poua Island: Obelisk Islet	9 29 30	140 04 45	......	......	......	......
	Nuka-Hiva Island: Port Tai-o-hae light	8 55 13	140 04 00	3 50	10 05	3.5	2.1
	Hiaou Island: S. pt	8 03 30	140 44 00	......	......	......	......
	Motu-ili Island: Summit, 130 ft	8 44 00	140 38 30	......	......	......	......
	Ua-Huka or Ua-Una Island: N. pt	8 54 00	139 33 30	......	......	......	......
	Fetouhouhou Island: NE. pt	7 55 00	140 34 40	......	......	......	......
	Caroline Islands: Solar Eclipse Transit Pier	10 00 01	150 14 30	4 00	10 14	1.1	0.7
	Vostok Island: Center	10 06 00	152 23 00	......	......	......	......
	Flint Island: S. extremity	11 25 23	151 48 34	......	......	......	......
	Malden Island: Flagstaff, W. side	4 03 00	155 01 00	......	......	......	......
	Starbuck Island: Flagstaff, W. side	5 37 00	155 56 00	......	......	......	......
	Penrhyn or Tongarewa Island: NNW. pt	8 55 15	158 07 00	6 00	12 15	1.5	0.9
	Jarvis Island: Center	0 22 33	159 54 11	......	......	......	......
	Reirson Island: Church	10 02 00	161 05 30	......	......	......	......
	Humphrey Island: N. pt	10 20 30	161 01 12	......	......	......	......
	Union or Tokelau Islands: Spot N. of Fakaofu or Bowditch Islet	9 23 02	171 14 46	6 00	12 13	2.4	1.4
	Union or Tokelau Islands: Nuku-nono, or SE. island, Duke of Clarence I	9 13 06	171 44 40	......	......	......	......
	Union or Tokelau Islands: Clump on S. island, Oatafu or Duke of York I	8 39 40	172 28 10	......	......	......	......
Phœnix Is.	Canton or Mary Island: N. pt	2 44 25	171 45 29	......	......	......	......
	Enderbury Island: W. pt	3 08 30	171 10 00	5 00	11 15	4.6	2.7
	Phœnix Island, N. pt	3 42 28	170 42 37	......	......	......	......
	Birneys Island: S. pt	3 34 15	171 32 07	......	......	......	......
	Gardners Island: Center	4 37 42	174 40 18	......	......	......	......
	McKean Island: Center	3 35 10	174 17 26	......	......	......	......
	Hulls Island: W. pt	4 30 95	172 13 28	......	......	......	......
			Long. E.				
Ellice Islands.	Mukulaelae or Mitchells Island: S. pt	9 18 00	179 50 00	......	......	......	......
	Funafuti or Ellice Island: E. pt	8 25 19	179 07 25	......	......	......	......
	Nukufetau or De Peysters Island: S. pt	8 04 02	178 28 51	......	......	......	......
	Vaitupu Island: S. end	7 32 00	178 41 01	......	......	......	......
	Nui or Netherland Island: S. pt	7 15 45	177 16 50	......	......	......	......
	Nauomaga Island: Center	6 12 00	176 16 30	......	......	......	......
	Niutao Island: Church	6 06 00	177 20 01	......	......	......	......
	Nanomea Island: Center	5 39 00	176 06 15	......	......	......	......

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE PACIFIC—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Ocean or Paanopa Island: Center (appx.).	0 52 00	169 35 00	....	....	....	....
	Pleasant Island: Center	0 25 00	167 05 00	....	....	....	....
	Indispensable Reefs: S. pt. of S. reef	12 50 15	160 26 00	....	....	....	....
	Rennel Island: SE. extreme	11 52 15	160 40 15	....	....	....	....
	W. end	11 33 45	159 55 00	....	....	....	....
Solomon Islands	San Cristoval Island: Point Wangalaha	10 17 32	161 33 30	6 45	0 33	3.3	2.0
	Guadalcanal Island: Wanderer Bay, mouth of Boyd Creek	9 41 47	159 39 30	....	....	....	....
	Florida Island: Mboli Harbor, Tree Islet.	9 01 30	160 27 20	....	....	....	....
	Malaita Island: Village, Mary I., Port Adam	9 30 00	161 27 40	....	....	....	....
	Stewart Islands: Largest islet	8 23 00	162 58 15	....	....	....	....
	Isabel Island: N. side of Cockatoo Islet	8 30 50	159 38 20	5 00	11 15	3.5	2.1
	Gizo or Shark Island: N. point village	8 05 40	156 50 15	....	....	....	....
	Choiseul Island: Choiseul Bay entrance.	6 42 40	156 23 16	....	....	....	....
	Treasury Islands: Observation Islet	7 24 30	155 34 00	....	....	....	....
	Bougainville Island: Husker Pt., Gazelle Harbor	6 35 00	155 05 00	12 00	5 47	2.7	1.6
	Buka Island: Cape North	5 00 00	154 35 00	....	....	....	....
	Lord Howe Group: Center, small SW. islet	5 38 00	159 21 00	....	....	....	....
	Center, small NE. islet	5 18 00	159 34 00	....	....	....	....
	NW. pt. of Hammond I	5 18 00	159 17 00	....	....	....	....
	Neu Pommern (New Britain), Blanche Bay: Matupi I. N. pt	4 14 12	152 11 35	9 00	2 45	2.1	1.3
	Duke of York Island: Makada Harbor, Spit Pt	4 06 25	152 06 15	....	....	....	....
	Neu Mecklenburg (New Ireland): Carteret Harbor, Cocoanut I	4 41 26	152 42 25	....	....	....	....
	Katharine Haven	3 11 00	151 35 30	....	....	....	....
	Holz Haven, E. side	2 47 30	150 57 35	2 50	9 03	2.4	1.4
	New Hanover Island: Water Haven, creek mouth	2 33 43	150 04 33	....	....	....	....
	North Haven anchorage	2 26 30	149 55 36	2 30	8 43	2.4	1.4
	St. Matthias Island: SW. extreme	1 35 00	149 37 00	....	....	....	....
Admiralty Is.	Admiralty Island: Nares Harbor, obs. islet	1 55 10	146 40 56	....	....	....	....
	St. Andrew Island: Violet Islet, 60 ft	2 25 40	147 28 35	....	....	....	....
	Jesus Maria Island: SE. pt	2 22 00	147 55 00	....	....	....	....
	Commerson Island: Center of largest islet.	0 45 00	145 17 00	....	....	....	....
	Anchorite Island: N. pt	0 53 15	145 33 04	....	....	....	....
	Hermit or Loaf Island: Pemé Islet	1 28 00	145 08 00	....	....	....	....
	Purdy Island: Mole Islet	2 51 00	146 15 00	....	....	....	....
New Guinea Island.	Point d'Urville: extreme	1 25 40	135 28 12	....	....	....	....
	Drei Cap Peninsula: Wass Islet	2 44 00	132 04 00	....	....	....	....
	Triton Bay: Fort Dubus, Dubus Haven	3 47 00	134 06 00	0 55	7 08	7.3	4.3
	Cape Walsche: Extreme	8 22 00	137 40 00	....	....	....	....
	Fly River: Free Islet, S. pt	8 41 00	143 36 04	....	....	....	....
	Port Moresby: N. end of Jane I	9 25 30	147 07 04	8 50	2 38	8.0	4.8
	Cape Rodney: Extreme	10 14 30	148 30 30	....	....	....	....
	South Cape: S. pt. Su Au I	10 43 35	150 14 20	9 15	3 00	8.1	4.8
	Hayter Island: W. end	10 37 00	150 40 34	8 25	2 12	5.8	3.4
	Cape Cretin: Cretin Islets	6 43 00	147 53 20	....	....	....	....

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE PACIFIC—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Louisiade Arch.	Trobriand Islands: NE. pt. Cape Denis	8 24 00	151 01 24	4 45	10 58	3.0	1.8
	Woodlark Islands: N. pt	9 03 30	152 47 00	7 05	0 53	4.2	2.5
	D'Entrecasteaux Is.: Ferguson I., SW. extreme	9 38 00	150 30 00				
	Well Island, E. pt	9 41 00	150 58 00				
	Normanby I., obs. islet	9 43 53	150 44 43				
	St. Aignan Island: Summit	10 42 00	152 42 04				
	Renard Islands: W. pt	10 52 40	152 47 12				
	Rossel Island: E. pt	11 23 25	154 08 00				
	Adele Island: S. extreme	11 29 10	154 25 14				
Coral Sea Arch.	Coringa Islands: Chilcott Islet	16 50 00	149 58 00				
	Herald Cays: NE. Cay	16 55 50	149 11 54				
	Tregosse Islands: S. islet	17 43 00	150 42 04				
	Lhou Reef: Observation Cay	17 07 20	152 06 20				
	Mellish Reef: Cay beacon	17 24 39	155 52 24				
	Bampton Island	19 08 00	158 40 00				
	Renard Island: Center	19 14 00	159 00 00				
	Wreck Reef: Bird Islet	22 10 30	155 28 24				
	Cato Island: Center	23 15 02	155 33 04				
Santa Cruz Islands.	Duff or Wilson Group: N. island	9 48 00	166 53 15				
	Matema or Swallow Group: Nimanu Islet	10 21 00	166 17 15				
	Tinakula Island: Summit, 2,200 ft	10 23 30	165 47 30				
	Nitendi Island: NE. pt., Cape Byron	10 40 00	166 00 30				
	Tapua Island: Basilisk Harbor, S. pt. of entrance	11 17 30	166 32 14				
	Vanikoro: Ocili village	11 40 24	166 57 45	4 50	11 05	3.8	2 3
New Hebrides Islands.	Torres or Ababa Island: Hayter Bay, Middle I	13 15 00	166 33 00				
	Vanua Lava Island: Port Patterson, Nusa Pt	13 48 00	167 30 31	6 40	0 30	3.8	2.3
	Santa Maria Island: Lasolara Anchorage	14 11 00	167 30 00				
	Aurora Island: Laka-rere	14 58 00	168 02 00				
	Mallicollo Island: Port Sandwich, pt. on E. side	16 26 00	167 47 15	4 38	10 50	3.8	1.9
	Vate or Sandwich Island: Havannah Harbor, Matapou Bay flagstaff	17 44 58	168 18 50	5 15	11 27	3.0	1 8
	Erromango Island: Dillon Bay, Pt. Williams	18 47 30	168 58 00				
	Tanna Island: Port Resolution, Mission	19 31 17	169 27 30				
	Erronan or Futuna Island: NW. pt	19 31 20	170 11 15				
	Aneityum Island: Port Anatom, Sand Islet	20 15 17	169 44 45	5 10	11 23	3.1	1.9
	Matthew Island: Peak, 465 feet	22 20 12	171 20 30				
	Hunter Island: Peak, 974 feet	22 24 02	172 05 15				
	Walpole Island: S. pt	22 38 07	168 56 45				
	Mitre Island: Center	11 55 00	170 10 00				
	Rotumah Island: Epipigi Peak	12 30 10	177 07 15	6 15	0 00	4.2	2.5
Fiji Islands.	Kandavu Island: N. rock Astrolabe Reef light	18 38 15	178 32 15				
	Mt. Washington, N. peak	19 07 09	177 57 09				
	Ngaloa Harbor, outer beacon	19 05 30	178 10 24	6 40	0 25	4.0	2.4
	Vatu Lele Island: S. pt	18 36 00	177 38 00				
	Ovalau Island: Levuka lighthouse	17 40 45	178 49 00				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE PACIFIC—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Fiji Islands.	Viti Levu Island: Summit of Malolo Islet	17 44 45	177 09 00				
	Suva Harbor, low light	18 06 50	178 24 40	6 30	0 15	3.6	2.2
	Mbega or Mbengha Island: Swan Harbor, Leaven Pt	18 22 00	178 06 53				
	Matuku Island: N. side of Matuku entrance	19 09 38	179 44 27				
	Moala Island: Rocks off N. pt	18 32 49	179 56 25				
	Ngau Island: Herald Bay, E. side	17 59 32	179 14 08				
	Wakaya Island: Rocky Peak	17 37 11	178 59 29				
	Makongai Island: Dilliendreti Peak	17 27 14	178 57 46				
	Goro Island: NW. pt	17 15 21	179 20 44				
	Vanua Levu Island: Mount Dana	16 42 01	178 54 15				
	Nandi, observation islet	16 57 53	178 48 32				
	Savu Savu Pt., extreme	16 49 19	179 16 08	6 00	12 13	4.3	2.6
			Long. W.				
	NE. Pt	16 08 00	179 58 46				
	Taoiuni Island: Somu-Somu town	16 46 00	179 51 00				
	Thikombia Island: E. hummock	15 44 45	179 54 26				
	Naitamba Island: Center	17 03 00	179 17 00				
	Vatu Vara Island: N. end, summit	17 25 33	179 32 17				
	Kanathea Island: S. pt	17 17 20	179 10 00				
	Vanua Mbalavu Island: NW. pt	17 10 00	179 05 45				
	Mango Island: Pier end	17 25 26	179 10 33	6 10	0 00	3.1	1.9
	Thithia Island: Highest peak	17 44 12	179 19 49				
	Tuvutha Island: Peak	17 39 33	178 50 27				
	Naian Island: Summit, 580 ft	17 59 00	179 04 00				
	Lakemba Island: Kendi Pt	18 14 10	178 52 00				
	Oneata Island: Summit of Loa I	18 25 46	178 27 04				
	Mothe Island: Summit	18 38 56	178 30 54				
	Mamuka Island: Center, 260 feet	18 46 00	178 44 00				
	Kambara Island: Highest peak	18 56 15	178 59 05				
	Totoya Island: Black Rock Bay, W. side	18 58 57	179 52 58	6 35	0 20	3.5	2.1
	Fulanga Island: W. bluff	19 03 00	178 47 25				
	Ongea Levu Island: Center	19 04 00	178 33 25				
	Vatoa or Turtle Island: Hummock	19 49 11	178 13 38	6 10	0 00	3.1	1.9
	Ono Islands: Peak	20 39 10	178 43 27				
	Michaeloff Island: Center	21 00 09	178 44 03				
	Simonoff Island: Center	21 01 39	178 49 47				
	Fatuna or Horne Island: Mt. Schouten	14 14 20	178 06 45				
	Uea or Wallis Island: Fenua-fu Islet	13 23 35	176 11 47	6 40	0 28	4.4	2.7
	Niua-fu or Good Hope Island: NW. extreme	15 34 00	175 40 40				
	Keppel Island: Center	15 52 00	173 52 00				
	Boscawen Island: Center	15 58 00	173 52 00				
Samoa Is.	Savaii Island: Paluale village	13 45 00	172 17 00				
	Upulo Is.: Apia Harbor, obs. spot	13 48 56	171 44 56	6 25	0 13	3.1	1.9
	Tutuila Island: Pago-Pago, obs. pt	14 18 06	170 42 14	7 00	0 45	2.7	1.6
	Manua Island: Village, NW. side	14 19 00	169 32 00	6 00	12 13	4.6	2.7
	Rose Island: Center	14 32 00	168 09 00				
	Niue or Savage Island: S. pt	19 10 00	169 50 00				
	Danger, or Bernardo, Is.: Middle rock	10 52 47	165 51 30				
	Suwarrow or Souwaroff Island: Cocoanut Islet	13 14 30	163 04 10	3 10	9 23	2.4	1.4
	Palmerston Islands: W. islet	18 05 50	163 10 00				
	Scilly Islands: E. islet	16 28 00	154 30 00				
	Bellingshausen Island: Center	15 48 00	154 31 00				
	Mopelia (Lord Howe) Island: Center	16 52 00	154 00 00				

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE PACIFIC—Continued.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Society Islands.	Maitea Island: Summit	17 53 00	148 05 00				
	Tahiti Island: Lighthouse	17 29 10	149 29 00	12 00	5 48	1.0	0.6
	Tubuai-Manu or Maia-iti I.: NW. pass	17 36 39	150 36 56				
	Eimeo Island: Talu Hbr., Vincennes Pt.	17 29 23	149 50 30				
	Huaheine Island: Lighthouse	16 42 30	151 01 28				
	Ulietea Island: Regent Pt.	16 50 00	151 27 21				
	Tahoa Island: Center	16 35 00	151 35 00				
	Bola-Bola Island: Otea-Vanua village	16 31 35	151 46 00	12 10	6 00	1.4	0.8
	Tubai or Motu-iti Island: N. pt. of reef	16 11 00	151 48 00				
	Marua or Maupili Island: Center	16 26 00	152 12 00				
Tuamotu Archipelago.	Ducie Island: NE. entrance	24 40 20	124 48 00				
	Pitcairn Island: Village	25 03 50	130 08 30				
	Henderson or Elizabeth Island: Center	24 21 20	128 19 00				
	Oeno Island: N. pt	24 01 20	130 41 00				
	Mangareva or Gambier Island: Flagstaff	23 07 36	134 57 54	1 50	8 03	2.4	1.4
	Marutea or Lord Hood Island: Center	21 31 30	135 33 05				
	Maria or Moerenhout Island: Center	22 01 00	136 10 15				
	Vahanga Island: W. pt	21 20 00	136 38 53				
	Morane or Cadmus Island: Center	23 07 50	137 06 15				
	Tureia or Carysfort Island: E. pt	20 46 20	138 27 45				
	Mururoa or Osnabrug Island: Obs. spot	21 50 00	138 56 30				
	Tematangi or Bligh Island: N. pt	21 38 00	140 38 45				
	Nukutipipi: SW. pt	20 43 00	143 03 15				
	Hereheretue or St. Paul Island: Center	19 53 17	144 57 00				
	Vanavana or Barrow Island: Center	20 46 07	139 08 45				
	Nukutavake or Queen Charlotte I.: N. pt.	19 16 30	138 48 30				
	Reao or Clermont Tonnere Island: NW. point	18 00 29	136 26 30				
	Puka-ruha or Serles Island: NW. pt	18 16 00	137 03 30				
	Vahitahi Island: W. pt	18 43 30	138 53 15				
	Ahunui or Byam Martin Island: NW. pt.	19 37 00	140 15 45				
	Pinaki or Whitsunday Island: E. pt	19 25 00	138 40 45				
	Tatakoto or Clerke Island: Flagstaff on western coast	17 19 30	138 26 26				
	Hao or La Harpe Island: NW. pass	18 05 20	140 59 30	2 40	8 55	2.4	1.4
	Paraoa or Gloucester Island: Center	19 08 45	141 41 10				
	Ravahere Island: S. pt	18 18 30	142 11 31				
	Reitoru or Bird Island: N. beach	17 49 35	143 05 23				
	Hikueru or Melville Island: E. pt	17 35 28	142 35 16				
	Tauere Island: NW. pt	17 20 30	141 29 43				
	Puka-puka Island: E. pt	14 49 00	138 46 45				
	Napuka Island: W. pt	14 12 00	141 15 37				
	Angatau or Araktcheff Island: W. pt	15 50 00	140 53 35				
	Tukume or Wolkonsky Island: NW. pt	15 44 20	142 08 40				
	Tuanske Island: NW. pt	16 39 10	144 14 45				
	Nihiru Island (Tuanake): SW. pt	16 44 29	142 53 34				
	Anaa Island: Islet in N. pass	17 20 20	145 30 54				
	Tepoto Island: N. pt	16 47 49	144 17 18				
	Haraiki or Crocker Island: SW. pt	17 28 41	143 31 17				
	Makemo or Phillips Island: W. pass	16 26 09	143 57 59				
	Fakarana or Wittgenstein Island: SE. pass	16 31 00	145 22 45				
	Taiaro or Kings I.: Middle of W. shore	15 43 15	144 38 34				
	Aratika Island: E. pt	15 30 00	145 24 45				
	Toau or Elizabeth Island: Amyot Bay	15 50 00	146 02 45				
	Takapoto Island: S. pt	14 43 00	145 11 00				
	Aheu Island: Lagoon Entrance	14 29 10	146 20 00				
	Rangiroa Island: E. pt	15 14 30	147 11 00	4 30	10 43	2.1	1.3
	Makatea Island: W. pt	15 50 30	148 15 00				
	Matahiva Island: W. pt	14 53 00	148 39 45				

MARITIME POSITIONS AND TIDAL DATA.

ISLANDS OF THE PACIFIC—Continued.

Coast.	Place.	Lat. S.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range Spg.	Range Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Juan Fernandez Island: Fort S. Juan Batista	33 37 36	78 50 02				
	Mas Afuera Island: Summit, 4,000 ft	33 46 00	80 46 00				
	St. Ambrose Island: N. part creek	26 18 07	79 54 56				
	St. Felix Island: Center	26 16 00	80 06 56				
	Sala y Gomez: NW. pt	26 27 41	105 28 00	4 00	10 15	3.3	2.0
	Easter Island: Cooks Bay, mission	27 10 00	109 26 00	0 40	6 53	2.8	1.7
	Rapa or Oparo Island: Tauna Islet	27 35 46	144 17 20	0 10	6 25	2.4	1.4
	Bass Islets (Morotiri): SE. islet, 344 ft	27 55 30	143 28 21				
	Tubuai or Austral Is., Vavitoa I.: Center	23 55 00	147 48 00				
	Tubuai I.: Flag-staff, N. side	23 21 45	149 35 35	3 00	9 13	2.4	1.4
	Rurutu I.: N. pt	22 29 00	151 23 41				
	Rimitara I.: Center	22 45 00	152 55 00				
Cook Islands.	Hull Island: NW. pt	21 47 00	154 51 00				
	Mangaia Island: Center	21 49 00	157 56 00				
	Rarotonga Island: NW. pt	21 11 35	159 47 00	6 00	12 15	2.7	1.7
	Mauki or Parry Island: Center	20 17 00	157 23 00				
	Mitiero Island: Center	20 01 00	157 34 00				
	Vatiu or Atiu Island: Center	20 04 00	158 08 00				
	Hervey Islets: Center	19 18 00	158 54 00				
	Aitutaki Island: Center	18 54 00	159 32 00				
Tonga Is.	Vavau Island: Port Valdes, Sandy Pt	18 39 02	174 01 00	6 20	0 10	3.8	2.3
	Kao Island: Summit, 5,000 ft	19 41 35	174 59 50				
	Tofua Island: Summit, 2,800 ft	19 45 00	175 03 00				
	Tongatabu Island: Lighthouse	21 08 00	175 12 00	6 20	0 10	3.8	2.3
	Minerva Reefs, N. Minerva: NE. side	23 37 06	178 55 45	7 50	1 35	5.5	3.3
	S. Minerva: S. side of entrance	23 55 00	179 07 45				
	Kermadec Is., Raoul or Sunday I.: Denham B. flagstaff	29 15 30	177 55 40	6 00	12 13	3.3	2.7
	Macauley I.: Center	30 15 00	178 31 45				
	Curtis I.: Center	30 35 00	178 37 00				
			Long. E.				
	Conway Reef: Center	21 44 45	174 37 45				
	Loyalty Is., Uvea or Halgan I.: Uvea Church	20 27 06	166 35 25				
	Lifu I.: Wreck Bay, NW. shore	20 46 00	167 02 30	6 30	0 18	4.2	2.5
	Mare or Britannia I.: S. pt	21 42 00	168 00 00				
New Caledonia.	Port Kanala: Observatory	21 29 12	165 58 50				
	St. Vincent Bay: Marceau I	22 00 10	166 03 30	5 40	11 52	3.3	2.0
	Noumea: Lighthouse	22 16 22	166 25 52	8 25	2 13	3.1	1.9
	Balari Pass: Amedée I. light	22 23 44	166 23 51				
	Port Alcmeme: Alcmene I	22 42 30	167 27 55	7 55	1 45	3.6	2.2
	Norfolk Island: Inner end of jetty	29 03 45	167 58 06	7 30	1 17	4.7	3.9
	Elizabeth Reef: Center	29 56 00	159 04 30				
	Lord Howe Island: S. end of middle beach	31 31 38	159 05 58	8 20	2 08	5.4	3.3
	Balls Pyramid: Summit, 1,816 ft	31 45 10	159 16 10				
	Macquarie Island: N. pt	54 19 00	158 56 00				
	Auckland Is.: Port Ross, Terror Cove	50 32 15	166 13 20	11 50	5 38	3.2	2.6
	Campbell Island: S. harbor, Shoal Pt	52 33 26	169 08 41	11 45	5 33	3.5	2.9
	Antipodes Island: Summit, 600 ft	49 42 00	178 43 05	3 20	9 30	5.3	4.3
	Bounty Islands: Anchorage N. I., West Group	47 43 00	179 00 27				
			Long. W.				
	Chatham Island, Whare-Kauri Island: Port Waitangi, Pt. Hanson	43 57 24	176 32 15				
	Chatham Island, Whare-Kauri Island: Port Hutt, Gordon Pt	43 49 03	176 42 00	5 22	0 23	2.5	2.1

MARITIME POSITIONS AND TIDAL DATA.

AUSTRALIA.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
North Australia.	Groate Eylandt: SE. pt	14 16 00	136 58 00				
	Bickerton Island: Summit	13 45 00	136 15 00				
	Cape Arnheim: Extreme	12 14 00	137 00 00				
	Cape Wilberforce: E. extreme	11 53 00	136 34 00	8 00	1 48	9.8	5.8
	Cape Wessel: Extreme	10 59 00	136 46 00				
	Dale Point: Extreme	11 36 00	136 07 00				
	Cape Stewart: Extreme	11 57 00	134 45 00				
	Liverpool River: W. pt. entrance	11 54 00	134 12 00	6 17	0 05	12.0	7.1
	Cape Croker: Extreme	10 57 00	132 36 30				
	Port Essington: Government house	11 22 02	132 09 18				
	Melville Island: Cape Van Diemen	11 08 00	130 19 00				
	Bathurst Island: Cape Fourcroy	11 51 00	129 58 00				
	Adelaide River: E. entrance pt	12 13 20	131 16 30	5 15	11 27	16.8	9.9
	Port Darwin: Charles Pt. light	12 23 20	130 37 00	4 57	11 18	17.0	10.0
	Port Patterson: Quail Islet	12 30 58	130 27 00	3 50	10 00	16.7	9.9
	Port Keats: Tree Pt	13 59 00	129 37 00	5 45	11 58	21.9	12.9
	Pearce Point: Extreme	14 25 50	129 20 42	6 45	0 27	23.0	13.6
	Victoria River: Water Valley	15 13 45	129 48 14				
Western Australia.	Cape Dussejour: Rock off cape	14 42 00	128 10 00				
	Cape Londonderry: Extreme	13 44 00	126 57 00				
	Cape Bougainville: Extreme	13 52 00	126 12 00				
	Cassini Island: S. pt	13 57 07	125 38 45				
	Cape Voltaire: Flat Hill	14 15 00	125 39 00				
	Barker Islets: Center	13 55 00	124 55 00				
	Montalivet Islands: W. islet	14 14 00	125 12 00				
	Maret Islets: N. islet	14 23 00	125 00 00				
	Colbert Islet: Center	14 51 00	124 42 00				
	Prince Regent River: Mount Trafalgar	15 16 36	125 07 00				
	Port Nelson: Careening beach	15 06 00	125 01 00				
	De Freycinet Islets: Beacon on summit	14 59 20	124 32 11				
	Red Islet: Center	15 13 15	124 14 00				
	Cockell Islet: W. pt	15 46 00	124 04 00				
	MacLeay Islets: Rock off N. end	15 52 00	123 45 00				
	Port Usborne: S. pt	15 39 25	123 36 27				
	Fitz Roy River: Escape Pt	17 24 25	123 39 47				
	Cape L'Evêque: Extreme	16 23 00	122 55 45				
	Lacepede Island: NW. islet	16 50 00	122 05 30				
	Cape Baskerville: Extreme	17 09 00	122 15 00				
	Cape Latouche Tréville: Extreme	18 29 00	121 54 00				
	Turtle Isles: Center of N. isle	19 54 00	118 48 00				
	Cape Lambert: Extreme	20 36 00	117 11 00	11 30	5 10	17.6	10.4
	Legendre Island: NW. extreme	20 19 00	116 45 00				
	Rosemary Island: W. summit	20 27 00	116 30 00				
	Enderby Island: Rocky Head	20 35 00	116 23 00				
	Montebello Island: N. extreme of reef	20 16 45	115 22 00				
	Barrow Island: N. pt	20 40 40	115 27 45				
	Northwest Cape: Extreme	21 46 41	114 10 08				
	Cape Cuvier: Extreme	24 00 00	113 21 00				
	Cape Inscription: Extreme	25 29 19	112 57 09				
	Houtman Rocks: N. islet	28 18 05	113 35 33				
	Port Gregory	28 12 00	114 14 30				
	Cape Leschenault: Extreme	31 18 00	115 30 00				
	Rottnest Island: Lighthouse	32 00 20	115 30 12				
	Perth (Fremantle): Arthur Head light	32 03 12	115 43 48	[10 16]	[3 43]	[2.1]	
	State Observatory	31 57 09	115 50 26				
	Peel: Robert Pt	32 27 00	115 44 00				
	Cape Naturaliste: Extreme	33 31 45	115 00 15				
	Cape Leeuwin: Lighthouse	34 21 55	115 08 00				
	D'Entrecasteaux Point: Extreme	34 52 00	116 01 00				
	Nuyts Point: Extreme	35 05 00	116 38 00				
	West Cape Howe: Extreme	35 09 00	117 40 00				
	Eclipse Islets: Summit of largest	35 11 54	117 53 45				
	King George Sound: Commissariat house near Albany jetty	35 02 20	117 54 04	[10 53]	[4 40]	[2.6]	

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

AUSTRALIA—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Western Australia.	Bald Isle: Center	34 55 00	118 27 00				
	Hood Point: Doubtful Isles	34 24 00	119 34 00				
	Recherche Archipelago: Termination Isle	34 30 00	121 58 00				
	Culver Point: Extreme	32 57 00	124 39 00				
	Dover Point: Extreme	32 34 00	125 30 00				
South Australia.	Fowler Point: Extreme	32 01 30	132 33 00	11 50	9 35	5.1	0.3
	Streaker Bay: Port Blanche	32 48 00	134 13 40				
	Coffin Bay: Mount Dutton	34 29 29	135 24 56	0 35	6 55	5.5	0.3
	Cape Catastrophe: W. pt	35 00 15	135 56 09				
	Neptune Isles: SE. islet	35 20 15	136 06 24				
	Port Lincoln: English Church	34 43 22	135 51 03				
	Franklin Harbor: Observation spot	33 44 08	136 57 22				
	Port Augusta: Flagstaff	32 29 42	137 45 24	8 20	2 15	11.4	0.7
	Port Victoria: Wardang Island hut	34 28 25	137 22 21				
	Cape Spencer: S. pt	35 18 21	136 53 30				
	Investigator Strait: Troubridge light	35 07 31	137 49 39				
	Port Wakefield: Lighthouse	34 12 00	138 09 00	4 31	10 45	10.2	0.6
	Port Adelaide: Wonga Shoal light	34 50 25	138 26 58	4 04	10 22	6.3	0.9
	Observatory	34 55 38	138 35 05				
	Cape Jervis: Lighthouse	35 36 45	138 05 29				
	Cape Borda: Lighthouse	35 45 30	136 34 39				
	Cape Willoughby: Lighthouse	35 51 00	138 07 45	4 00	10 15	5.8	0.3
	Port Victor: Flagstaff	35 34 06	138 37 09				
	Cape Jaffa: Margaret Brock lighthouse	36 57 00	139 39 39				
	Cape Northumberland: Lighthouse	38 04 18	140 39 40	11 52	5 40	4.2	0.2
Victoria.	Cape Nelson: S. extreme	38 26 00	141 32 39				
	Portland Bay: Lawrence Rock	38 24 39	141 40 02	0 20	6 35	2 7	2 1
	Port Fairy: Griffith Island summit	38 23 47	142 14 37				
	Cape Otway: Lighthouse	38 51 45	143 30 39				
	King Island: Cape Wickham light	39 35 38	143 57 03				
	Port Phillip: Point Lonsdale light	38 18 00	144 37 00	10 43	4 30	2.5	1.9
	Geelong: Customhouse	38 08 52	144 21 47	2 02	8 20	3.0	2.3
	Melbourne: Observatory	37 49 53	144 58 35	2 19	8 41	1.9	1 5
	Cape Schanck: Lighthouse	38 29 42	144 52 51				
	Port Western: Extreme of W. head	38 29 15	145 01 34				
	Wilson Promontory: Light, SE. pt	39 08 00	146 25 16				
	Kent Island: Deal Island light	39 25 45	147 18 39				
	Flinders Is.: Strzelecki Peaks, SE. peak	40 11 45	148 04 00				
	Goose Island: Light on S. end	40 18 40	147 47 39	10 38	4 25	8.1	6.2
	Banks Strait: Swan Island light	40 43 40	148 07 24				
	Port Albert: Lighthouse	38 45 06	146 37 43				
	Gabo Island: Lighthouse	37 34 15	149 55 10	8 40	2 27	4.5	3.4
	Cape Howe: East extreme	37 30 10	149 58 39				
New South Wales.	Cape Green: SE. pt	37 15 40	150 03 04				
	Twofold Bay: Lookout Pt. light	37 04 18	149 54 45	8 05	1 52	5.2	3.1
	Dromedary Mountain: Summit	36 18 30	150 01 34				
	Montagu Island: Lighthouse	36 14 30	150 13 34	8 20	2 07	5.3	3.2
	Bateman Bay: Observation head	35 43 58	150 12 34				
	Ulladulla: Inner end of pier	35 21 41	150 29 29	8 20	2 07	5.4	3.3
	Jervis Bay: Lighthouse	35 09 15	150 46 26				
	Kiama Harbor: Outer extreme of S. head	34 40 25	150 52 19				
	Wollongong: Summit of head	34 25 30	150 55 14				
	Sydney: Observatory	33 51 41	151 12 23	8 40	2 27	4.2	2.5
	Port Jackson: Outer S. Head light	33 51 30	151 18 15				
	Broken Bay: Baranjo Head light	33 35 00	151 20 30				
	Newcastle: Nobby Head light	32 55 15	151 48 19	8 35	2 23	4.7	2.8
	Port Stephens: Lighthouse	32 45 10	152 13 20	8 15	2 00	5.8	3.6
	Sugar Loaf Point: Lighthouse	32 26 20	152 33 40				
	Port Macquarie: Entrance	31 25 30	152 55 19	9 00	2 46	4.1	2.4
	Solitary Islands: S. Isle light	30 12 00	153 17 00				
	Clarence River: S. Head light	29 25 30	153 23 10	8 15	2 00	4.0	2.4

MARITIME POSITIONS AND TIDAL DATA.

AUSTRALIA—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
Queensland.	Richmond River: N. Head light	28 51 30	153 35 55				
	Brisbane: Signal station, Fisherman Is.	27 23 22	153 10 31	10 45	4 30	6.4	3.9
	Observatory	27 28 00	153 01 36				
	Lookout Point: Extreme	27 26 20	153 33 50				
	Cape Moreton: Lighthouse	27 02 10	153 28 04				
	Double Island Point: Lighthouse	25 56 00	153 13 00				
	Indian Head: Extreme	25 00 15	153 23 00				
	Sandy Cape: Lighthouse	24 43 20	153 13 40				
	Burnett River: S. Head light	24 45 00	152 25 00				
	Lady Elliot Islet: Lighthouse	24 07 00	152 45 15				
	Bustard Head: Lighthouse	24 01 20	151 41 04				
	Rodd Bay: Spit end	24 01 20	151 37 15				
	Port Curtis: Gatcombe Head light	23 53 00	151 23 50				
	Cape Capricorn: Lighthouse	23 29 30	151 14 04				
	Port Bowen: Observation rock	22 31 40	150 45 44				
	Percy Isles: Pine I. light	21 39 00	150 14 00				
	Northumberland Isles: Summit of Prudhoe I	21 19 15	149 43 30				
	Cape Palmerston: N. extreme	21 32 00	149 31 04				
	Cape Conway: SE. pt	20 32 20	148 58 00				
	Port Molle: S. side of entrance	20 18 50	148 53 15				
	Cumberland Island: Whitsunday I., summit on W. side	20 15 30	149 00 00				
	Port Denison: Obs. pt., W. side of Stone Isle	20 00 50	148 16 54	10 05	3 53	9.0	5.4
	Gloucester Island: Summit near N. end	19 57 30	148 27 34				
	Holborne Islet: Center	19 41 50	148 23 00				
	Cape Bowling Green: Lighthouse	19 19 20	147 27 40				
	Cape Cleveland: Lighthouse	19 11 25	147 01 10				
	Palm Islands: SE. point of SE. island	18 45 30	146 42 50				
	Rockingham Bay: Peak of Goold Isle	18 09 30	146 11 04				
	Barnard Island: Lighthouse	17 40 40	146 11 00				
	Frankland Island: High islet	17 09 45	146 02 30				
	Cape Tribulation: Extreme	16 04 20	145 29 34				
	Hope Island: S. islet	15 45 00	145 28 30				
	Cook Mountain: Summit	15 29 45	145 17 30	8 55	2 43	7.5	4.5
	Cape Bedford: SE. extreme	15 16 30	145 23 15				
	Murdock Point: Extreme	14 37 15	144 57 30				
	Cape Melville: NE. extreme	14 10 00	144 32 34				
	Flinders Island: N. extreme of N. island	14 07 45	144 15 19				
	Claremont Point: Extreme	14 00 30	143 42 15				
	Cape Sidmouth: Extreme	13 24 45	143 36 19	9 00	2 47	9.6	5.8
	Cape Direction: NE. extreme	12 51 00	143 34 00				
	Cape Grenville: Extreme	11 58 15	143 15 15				
	Sir Charles Hardy Island: N. extreme of SE. isle	11 55 00	143 29 00				
	Bird Island: NW. isle	11 46 30	143 06 00				
	Hannibal Isles: E. isle	11 36 30	142 56 19				
	Cape York: Sextant Rock	10 41 30	142 32 24	1 00	7 10	8.0	4.7
	Mount Adolphus: Summit	10 37 45	142 39 20				
	Travers Isles: Center	10 22 00	142 21 19				
	Prince of Wales Island: Cape Cornwall, extreme	10 46 00	142 10 50				
	Booby Island: Center	10 36 05	141 53 49	4 20	10 30	7.8	4.7
	Flinders River: Entrance	17 36 40	140 37 06				
	Albert River: Kangaroo Pt	17 35 10	139 45 56				
	Sweers Island: Inscription Pt	17 06 50	139 38 36				

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

TASMANIA.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int.		Range.	
				H. W.	L. W.	Spg.	Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Cape Portland: NW. pt	40 44 15	147 56 09				
	Port Dalrymple: Low Head light	41 03 25	146 47 54	11 10	5 00	9.0	6.9
	Port Sorrell: NW. entrance head	41 07 05	146 33 30				
	Port Frederick: Entrance	41 10 00	146 24 30				
	Leven River: W. entrance head	41 08 30	146 12 00				
	Emu Bay: Blackman Pt	41 02 50	145 56 39				
	Hunter Island: N. pt	40 23 40	144 47 45				
	Cape Grim: Outer Doughboy Islet	40 40 10	144 39 44				
	Albatross Islet: N. pt	40 22 00	144 39 19				
	Arthur River: Entrance	41 04 00	144 44 00				
	Pieman River: Rocks close to entrance	41 41 00	144 57 00				
	Macquarie Harbor: Entrance Islet	42 11 37	145 12 34	7 20	1 07	2.7	2.1
	Cape Sorrell: Lighthouse	42 11 00	145 10 30				
	Port Davey: Pollard Head	43 19 00	145 53 00				
	Southwest Cape: Extreme pt	43 33 30	146 01 04				
	Mewstone Rock: Center	43 44 30	146 22 04				
	Cape Bruny: Lighthouse	43 29 40	147 08 49				
	Bruny Island: Penguin Islet	43 21 00	147 23 40				
	Hobart Town: Transit of Venus station	42 53 25	147 20 07	8 05	1 52	4.2	3.2
	Cape Pillar: Tasman Islet	43 14 00	148 02 00				
	Cape Frederik Hendrik: Extreme	42 52 00	148 00 00				
	Freycinet Peninsula: Summit	42 13 00	148 18 04				
	St. Patrick Head: N. pt	41 34 00	148 19 30				
	Eddystone Point: Extreme	40 59 40	148 20 50				

NEW ZEALAND.

Coast.	Place.	Lat. S.	Long. E.	H. W.	L. W.	Spg.	Neap.
North Island.	Three Kings Islands: NE. extreme of NE. island	34 06 20	172 08 49				
	North Cape: Cape Islet	34 25 07	173 03 34				
	Parenga-renga Harbor: Kohan Pt	34 31 00	173 00 54				
	Maunganui Harbor: White Pt	35 00 20	173 32 39				
	Wangaroa Harbor: Peach Islet	35 01 44	173 45 48	7 40	1 30	6.4	4.5
	Bay of Islands: Motu Mea Islet	35 17 00	174 06 06	7 26	1 55	5.9	4.2
	Wangaruru Harbor: Grove Pt	35 23 48	174 21 24	7 15	1 05	6.5	4.6
	Wangari Harbor: Loot Pt	35 51 09	174 31 14	7 05	0 55	6.7	4.8
	Great Barrier Island: Needles Pt	36 01 15	175 25 34				
	Auckland Harbor: Lighthouse	36 50 06	174 51 00	7 20	1 10	10.8	7.7
	Coromandel Harbor: Tuhnia I	36 48 35	175 24 34	7 05	0 55	10.7	7.6
	Cape Colville: N. pt	36 28 20	175 21 04				
	Cuvier Island: Lighthouse	36 26 20	175 49 00				
	Tauranga Harbor: Mount Maunganui, 860 ft	37 36 25	176 10 14	7 05	0 55	6.1	4.4
	White Island: Summit, 863 ft	37 30 00	177 10 49				
	Cape Runaway: Extreme	37 30 45	177 59 34	8 10	2 00	6.6	4.7
	East Cape: Islet, 420 ft	37 40 00	178 35 09	8 00	1 50	6.8	5.8
	Tolaga Bay: Matu-heka Islet	38 20 50	178 20 14				
	Mahia Peninsula: S. extreme of Portland I	39 18 00	177 53 15				
	Ahuriri Harbor: Lighthouse	39 28 30	176 54 14	6 05	12 15	3.5	3.0
	Kidnappers Cape: Extreme	39 38 00	177 06 44				
	Cape Palliser: Lighthouse	41 36 45	175 18 45	4 40	10 50	5.7	4.9
	Port Nicholson: Pencarrow light	41 21 40	174 51 04				
	Wellington: Queens Wharf light	41 17 17	174 47 25	4 52	10 54	3.6	3.1
	New Observatory	41 17 04	174 46 04				
	Mana-watu River: Lighthouse	40 27 10	175 14 40	9 40	3 30	6.3	5.4
	Wanganui River: N. head	39 57 00	174 59 44				
	Egmont Mountain: Summit, 8,270 ft	39 18 00	174 03 59				
	New Plymouth: Flagstaff	39 03 35	174 04 35	9 15	3 05	11.6	8.2
	Kawhia Harbor: S. head	38 04 50	174 48 04	9 10	3 00	11.9	8.5

MARITIME POSITIONS AND TIDAL DATA.

NEW ZEALAND—Continued.

Coast.	Place.	Lat. S.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
North Island.	Aotea Harbor: S. head	37 59 35	174 50 04	......	......	......	....
	Whaingaroa Harbor: S. entrance pt	37 46 22	174 52 19	9 08	2 55	12.3	8.7
	Manukau Harbor: Paratutai flagstaff	37 03 00	174 31 14	9 05	2 50	12.6	9.0
	Kaipara Harbor: Lighthouse	36 23 00	174 08 00	9 00	2 50	10.0	7.1
	Hokianga River: Flagstaff at entrance	35 32 05	173 21 59	8 40	2 30	9.2	6.5
South Island.	Cape Campbell: Lighthouse	41 44 00	174 17 14	4 45	11 00	7.5	6.5
	Port Cooper: Lyttleton customhouse	43 46 40	172 44 17	3 45	10 00	7.4	5.8
	Akaroa Island: Lighthouse	43 54 00	173 00 20	......	......	......	....
	Ashburton River: N. entrance pt	44 04 50	171 48 34	......	......	......	....
	Waitangi River: N. entrance head	44 54 50	171 11 14	......	......	......	....
	Otago Harbor: Taivoa Head light	45 46 55	170 44 02	3 31	9 39	5.6	4.4
	Molyneux Bay: Landing place	46 24 05	169 47 53	......	......	......	....
	Nugget Point: Lighthouse	46 27 10	169 50 04	......	......	......	....
	Bluff Harbor: Lighthouse	46 37 00	168 23 00	1 05	7 15	7.8	6.2
	Tewaewae Bay: Pahia Pt	46 20 40	167 42 19	......	......	......	....
	Solander Islands: Summit, 1,100 ft	46 36 00	166 54 04	......	......	......	....
	Preservation Inlet: Lighthouse	46 10 00	166 38 15	11 10	5 00	7.5	5.9
	West Cape: Extreme	45 54 50	166 25 49	......	......	......	....
	Queenstown: U. S. Tr. of Venus station	45 02 07	168 40 06	......	......	......	....
	Milford Sound: Freshwater Basin	44 40 20	167 54 45	......	......	......	....
	Cascade Point: N. extreme	44 00 30	168 21 34	......	......	......	....
	Grey River: Entrance	42 26 20	171 11 54	10 10	4 00	9.8	7.7
	Hokitika: Entrance light	42 42 20	170 59 30	10 20	4 10	9.5	7.5
	Cape Foulwind: Lighthouse	41 45 40	171 27 44	......	......	......	....
	Cape Farewell: Extreme	40 29 50	172 41 04	......	......	......	....
	Nelson: Bowlder Bank light	41 16 05	173 17 30	9 55	3 45	12.0	9.4
	D'Urville Island: Port Hardy	40 46 35	173 54 04	9 45	3 35	11.6	9.2
	Port Gore: Head of Melville Cove	41 01 55	174 11 22	......	......	......	....
	Port Underwood: Flag Pt	41 20 28	174 08 24	6 00	12 15	7.6	6.6
Stewart I.	Port William: Howell's house	46 50 30	168 05 34	......	......	......	....
	Paterson Inlet: Glory Cove	46 58 30	168 09 54	1 00	9 15	7.8	6.2
	Port Adventure: White Beach, S. end	47 03 52	168 10 57	......	......	......	....
	Port Pegasus: Cove abreast Anchorage I.	47 11 40	167 40 51	11 45	5 40	7.9	6.2
	Codfish Island: NW. extreme	46 45 45	167 36 49	......	......	......	....
	Snares Islands: SW. islet	48 06 43	166 27 44	......	......	......	....

THE ARCTIC REGIONS.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
	Cape Walsingham: Extreme	66 00 00	69 28 00	......	......	......	....
	Mile Island: N. pt	64 04 00	77 50 00	......	......	......	....
	Marble Island: E. end	62 33 00	91 06 00	4 00	10 15	12.0	5.1
	Cape Kendall: Extreme	63 42 00	87 15 00	......	......	......	....
	Iglooik Island: E. pt	69 21 00	81 31 00	6 50	0 40	8.0	4.2
	Victoria Harbor: N. shore	70 09 17	91 30 33	......	......	......	....
	Elizabeth Harbor: Entrance	70 38 14	92 10 56	......	......	......	....
	Magnetic Pole, 1831	70 05 00	96 47 00	......	......	......	....
	Port Neill: N. pt. of entrance	73 09 13	89 00 54	......	......	......	....
	Port Bowen: N. cove	73 13 39	88 54 48	......	......	......	....
	Batty Bay: S. pt. of entrance	73 13 00	91 08 00	......	......	......	....
	Port Leopold: Whaler Pt	73 50 05	90 12 00	11 38	5 29	5.5	2.9
	Careys Islands	76 49 00	73 10 00	......	......	......	....
	Discovery Harbor	81 04 40	64 45 00	......	......	......	....
	Alert's Winter Quarters	82 27 00	61 18 00	10 35	4 20	2.6	1.0
	Cape Joseph Henry: N. extreme	82 40 00	63 38 00	......	......	......	....
	Cape Hecla: N. extreme	82 54 00	64 45 00	......	......	......	....
	Cape Columbia: Extreme	83 07 00	70 20 00	......	......	......	....
	Melville Island: Winter Harbor	74 47 10	110 48 15	1 20	7 40	3.8	1.9
			Long. E.				
	North Cape	68 55 00	179 57 00	......	......	......	....

APPENDIX IV.

MARITIME POSITIONS AND TIDAL DATA.

THE ARCTIC REGIONS—Continued.

Coast.	Place.	Lat. N.	Long. E.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Liakhov Islands: E. pt. of New Siberia	75 10 00	150 30 00				
	Cape Tscheljuskin: E. pt	77 41 00	104 01 00				
	Nova Zembla: Vaigats I., N. pt	70 25 00	59 10 00				
	Cape Costin (Kostina)	70 55 00	53 01 50	10 00	3 50	7.0	4.0
	NE. pt., Cape Desire	76 58 00	65 40 00				
	Franz Josef Land: Wilczek I	79 55 00	58 45 00				
	Mezen: Epiphany Church	65 50 18	44 17 00				
	Morjovetz Island: Lighthouse	66 45 50	42 30 00				
	Archangel: Trinity Church	64 32 06	40 33 30	7 18	2 00	2.2	1.3
	Jighinsk Island: Lighthouse	65 12 17	36 51 30	5 05	11 30	3.8	2.1
	Onega: St. Michael's Church	63 53 36	38 08 30	9 02	3 10	9.1	5.2
	Salovetski: Lighthouse	65 07 00	35 37 00				
	Cape Sviatoi Nos: Lighthouse	68 08 51	39 48 54	9 05	2 55	13.9	7.8
	Bear Island	74 30 00	20 00 00				
	Spitzbergen Island: S. cape	76 35 00	17 23 00				
	Cloven Cliff	79 50 00	11 40 30				
	Danes I., Robbe Bay	79 42 00	11 07 00	0 14	6 25	5.3	3.0
		Lat. N.	Long. W.				
Greenland.	Cape Morris Jesup	83 39 00	30 40 00	(approx)			
	Thank God Harbor	81 38 00	61 44 00	12 14	5 58	5.4	2.0
	Cape York: Extreme	75 55 00	65 30 00				
	Upernivik: Flagstaff	72 47 48	55 53 42	10 50	4 38	8.0	3.0
	Proven: Village	72 20 42	55 20 00				
	Omenak Island: Village	70 40 00	51 59 00				
	Godhavn: Village	69 14 04	53 24 07				
	Jacobshavn: Village	69 13 12	50 56 30				
	Claushavn: Village	69 07 30	50 55 30				
	Christianshaab: Village	68 49 06	51 00 00				
	Egedesmunde: Village	68 42 30	52 46 00				
	Whalefish Island: Boat Inlet	68 58 30	53 27 00	8 05	1 52	7.5	3.6
	Holsteinberg: Village	66 55 54	53 40 18	6 20	0 07	10.0	4.8
	Kangamint	65 48 42	53 23 00				
	Ny Sukkertop: Village	65 24 30	52 54 00				
	Godthaab: Flagstaff	64 10 36	51 45 48	6 40	0 27	12.5	6.0
	Sermelik Fjord: Kasuk Peak	63 29 12	51 10 48				
	Fiskernaes: Village	63 05 12	50 43 36				
	Jensen Nunatak: Peak	62 50 00	48 57 00				
	Ravn Storo: Peak	62 42 36	50 20 48				
	Frederikshaab: Church	61 59 36	49 44 00	6 12	0 00	9.0	3.6
	Kangarssuk Havn: Village	61 28 20	48 51 00				
	Arsuk: Pingo Beacon	61 10 24	48 26 00	6 15	0 03	12.0	4.8
	Kajartalik Island: Summit	61 09 42	48 30 42				
	Ivigtuk: House	61 12 12	48 10 30				
	Bangs Havn: Anchorage	60 47 30	47 52 00				
	Aurora Harbor	60 48 36	47 46 48				
	Julianshaab: Village	60 43 07	46 01 00	4 56	11 09	7.0	2.8
	Neunortalik: Village	60 08 12	45 16 00	5 33	11 46	8.6	3.4
	Frederiksthal: Village	60 00 00	44 40 00	2 55	9 10	9.4	3.8
	Cape Farewell: Staten Huk	59 49 00	44 01 42	4 00	10 13	7.5	3.0
	Aleuk Islands: Center	60 09 00	42 55 00				
	Cape Tordenskjold: Extreme	61 25 00	42 15 00				
	Cape Bille: Extreme	62 01 00	42 00 00				
	Cape Juul: Extreme	63 14 00	40 50 00				
	Cape Lowenorn: Extreme	64 30 00	39 30 00				
	Dannesbrog Island: Beacon	65 18 00	38 30 00				
	Ingolsfjeld	66 19 02	35 11 00				
	Rigny Mount: Summit	69 00 12	26 10 24				
	Pendulum Islands	74 40 00	18 17 00	11 05	4 53	6.7	3.9
	Cape Philipp Broke	74 55 00	17 33 00	11 10	4 58	3.7	2.1
	Cape Bismarck: Extreme	76 47 00	18 40 00				

MARITIME POSITIONS AND TIDAL DATA.

THE ARCTIC REGIONS—Continued.

Coast.	Place.	Lat. N.	Long. W.	Lun. Int. H. W.	Lun. Int. L. W.	Range. Spg.	Range. Neap.
		° ′ ″	° ′ ″	h. m.	h. m.	ft.	ft.
	Jan Mayen Island: Mt. Beerenberg, 6,870 ft	71 04 00	7 36 00	......	......	......	......
	Youngs Foreland, or Cape Northeast	71 08 00	7 26 00	......	......	......	......
	Mary Muss Bay	71 00 00	8 28 00	11 21	5 06	3.8	2.2
Iceland.	**Langanaes Point**	66 22 45	14 30 46	......	......	......	......
	Rissnaes Point	66 32 40	16 10 24	......	......	......	......
	Grimsey Norddranger: Tr. Station	66 33 42	17 57 36	......	......	......	......
	Skagataas Point	66 07 30	20 05 26	......	......	......	......
	North Cape: **Kalfatindr**	66 27 29	22 23 04	......	......	......	......
	Straumness Point	66 26 30	23 08 00	......	......	......	......
	Fugle or Staabierg Huk: Point	65 30 15	24 31 26	......	......	......	......
	Snaefells Yokul: Tr. Station	64 48 04	23 45 08	......	......	......	......
	Reykiavik: Observatory	64 08 40	21 55 00	5 10	11 25	14.5	8.4
	Cape **Skagi**: Lighthouse	64 04 09	22 39 04	......	......	......	......
	Reykianaes: Lighthouse	63 48 06	22 39 00	......	......	......	......
	Ingolfshofde: Tr. Station	63 48 19	16 36 13	......	......	......	......
	Papey Island: Tr. Station	64 35 42	14 08 31	......	......	......	......
	Reythur Fjeld: Tr. Station	64 55 27	13 41 10	......	......	......	......
	Balatangi: Lighthouse	65 16 14	13 32 22	......	......	......	......
	Dia Fjeld: Tr. Station	65 45 00	14 23 35	......	......	......	......

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REGIONS AND COASTS.

REGIONS AND COASTS—continued.

PLACES.

PLACES—continued.

PLACES—continued.

PLACES—continued.

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PLACES—continued.

FLACES—continued.

PLACES—continued.

PLACES—continued.

PLACES—continued.

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