NAVIGATION

ILLUSTRATED BY DIAGRAMS

By

ALFRED GOLDSBOROUGH MAYOR

J. B. LIPPINCOTT COMPANY

NAVIGATION

ILLUSTRATED BY DIAGRAMS

NAVIGATION

ILLUSTRATED BY DIAGRAMS

BY

ALFRED GOLDSBOROUGH MAYOR

Licensed Yacht Master, Volunteer Instructor in Navigation at Princeton University, Director of the Department of Marine Biology, Carnegie Institution of Washington.

PHILADELPHIA AND LONDON

J. B. LIPPINCOTT COMPANY

1918

Electrotyped and Printed by J. B. Lippincott Company
The Washington Square Press, Philadelphia, U. S. A.

PREFACE

This book is intended for the use of young men of limited mathematical training who hope to qualify as Ensigns in the United States Navy, or for officers in the Naval Reserve, or Merchant Marine. The text is clarified by a far fuller use of diagrams than in other works of similar scope, for the author believes in graphic explanations whenever these are possible. The work is of a practical character and deals with the subject from the modern standpoint, leading up to an understanding of the value of Sumner lines and St. Hilaire's method.

The endeavor has been made to use simple language and to avoid mathematical abstractions and exercises that are of little practical value to the navigator.

No knowledge of mathematics other than simple arithmetic is pre-supposed, yet all the important methods used at sea are dealt with, and when possible illustrated by diagrams and by examples, for it is realized that in time of war one must be prepared on the instant to make use of the best method of which the situation permits, and a thorough and broad knowledge of navigation may be the means of rendering important service to one's country, as well as securing the safety of the ship. Constant reference is made to the tables in the 1917 edition of the "American Practical Navigator," Bowditch, published by the U. S. Hydrographic Office, and the American Nautical Almanac for the year 1918 is referred to in most of the examples, so the student is advised to procure these two works for use in connection with this book.

ALFRED G. MAYOR.

JUNE, 1918.

CONTENTS

ILLUSTRATIONS

NAVIGATION

ILLUSTRATED BY DIAGRAMS

CHAPTER I

THE COMPASS

Of all instruments, the compass is the most essential to the navigator, nor is it likely that the modern gyroscope will ever wholly replace the more reliable though less convenient magnetic needle. The history of its invention is lost in the obscurity of ancient times, but the credit appears to belong to the Chinese, who used the south-pointing end of their needle as that from which all other directions were reckoned.

The use of the compass was probably introduced into Europe in some round-about way through the Arabs or Moors, and as early as 1391; Chaucer states that " ship men " used a compass with 32 points.

When the compass appeared in Europe, however, the north-seeking end was considered to be the prime cardinal point, and is usually decorated, even to-day, by a fleur-de-lis or other conspicuous device.

N., S., E., and W., Fig. 1, are called cardinal points, while NE., SE., SW., and NW. are the inter-cardinals. All other points are referred to these. Thus in the figure of the compass-card, we have N., N. by E., NNE., NE. by

N., NE., NE. by E., ENE., E. by N., and E.; and so on all around through the 32 points.

Unluckily, the compass-card was devised long before

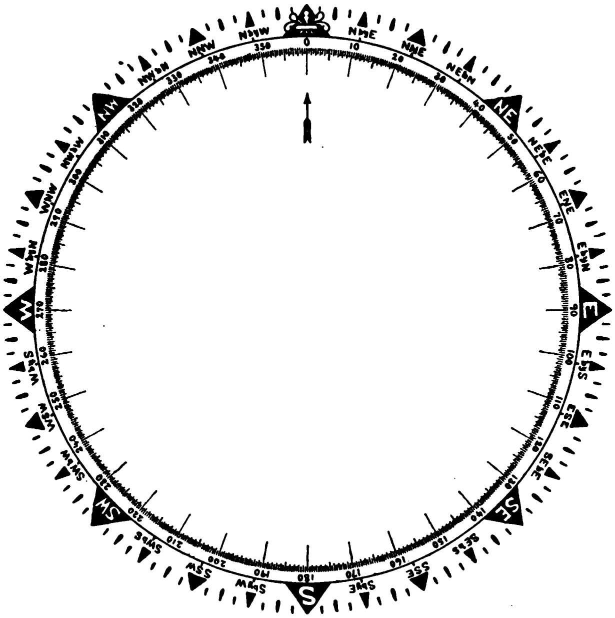


FIG. 1.—The mariner's compass, showing degrees and quarter points.

the days when it was possible to steer a course to a degree; most sailing vessels being content even to-day to make their courses to within a quarter of a point or roughly nearly 3°.

Accordingly, each interspace between successive points is commonly divided into quarters, or in the larger compasses into eight divisions, called quarter or one-eighth points.

In boxing the compass, it is the custom to refer these fractional points to the nearest cardinal or intercardinal point. Thus N. ¾ E., *not* N. by E. ¼ N.; NE. ⅝ N., *not* NE. by N. ⅜ E. In other respects, the compass is boxed from N. or S. towards E. or W. Thus N. by E. ¾ E., SE. by E. ⅝ E., S.W. ⅞ W., etc. A little study of the compass-card will make this clear.

It is perhaps unfortunate that the compass was not divided into 36 points of 10° each instead of the 32 points we have inherited from mediæval times, but we will probably always have to put up with our compass-point interval of 11¼°.

Despite the fractions this system often introduces, it has its conveniences, for it is easy to mentally divide a right angle into two halves of 4 points each; and these again into half intervals of 2 points, and then again into one-point intervals. Cultivate the habit of estimating angles in terms of points, and it will be of great aid to you in sailing.

We may name courses in relation to the N. and S. points of the compass: Thus, one-point courses would be N. by E., N. by W., S. by E., or S. by W.; four-point courses would be NE., SE., SW., or NW., etc.

We could also make use of degrees in the same manner, the four-point courses being N. 45° E., S. 45° E., S. 45° W., and N. 45° W.

These methods of indicating courses are most convenient in solving problems in dead reckoning, but for general purposes the modern Naval compass is divided into 360° beginning with N. Thus E. is 90°, S. 180°, W. 270°, and N. 360° or 0°.

This method has the advantage of precision and conciseness. Thus a course of 225° is S. 45° W. and nothing else; whereas if we merely called it a four-point course, we might be confused, for there are four courses of four-points.

The table on page 15, showing the relationship between compass designations, points, and angular measure, may be of service in determining courses.

With all its crudeness and mediævalism, however, the compass-card when divided into points has its advantages. It is easy to steer a course of say NE. ½ N. for we hold the lubber-point midway between the conspicuous black marks indicating NE. and NE. by N. If, on the other hand, there were no such aids to the eye, we would find it very difficult to keep the ship on 39½° which would be practically the same course designated in the modern manner.

VARIATION

Unfortunately for the convenience of the sailor, there are few places on the earth wherein the compass points to the true north, and even in these, slow changes take place. Thus at London between 1580 and 1692 the needle changed from 11° 15′ E. to 6° W. of the true north.

This geographical error of the compass is called *variation*, and is shown on the compass-rose on all modern charts, accompanied by a statement of its annual change. For

TABLE.

Compass designation of the course north to east to south	Course in points from north or south	Course in angular measure		Compass designation of the course south to west to north	Course in points from north or south	Course in angular measure	
N.	0 from N.	0°	0′	S.	0 from S.	180°	0′
N. by E.	1 from N.	11	15	S. by W.	1 from S.	191	15
N. N. E.	2 from N.	22	30	S. S. W.	2 from S.	202	30
NE. by N.	3 from N.	33	45	SW. by S.	3 from S.	213	45
NE.	4 from N.	45		SW.	4 from S.	225	
NE. by E.	5 from N.	56	15	SW. by W.	5 from S.	236	15
ENE.	6 from N.	67	30	WSW.	6 from S.	247	30
E. by N.	7 from N.	78	45	W. by S.	7 from S.	258	45
East	8 from S.	90°	0′	*West*	8 from N.	270°	0′
E. by S.	7 from S.	101	15	W. by N.	7 from N.	281	15
ESE.	6 from S.	112	30	WNW.	6 from N.	292	30
SE. by E.	5 from S.	123	45	NW. by W.	5 from N.	303	45
SE.	4 from S.	135		NW.	4 from N.	315	
SE. by S.	3 from S.	146	15	NW. by N.	3 from N.	326	15
SSE.	2 from S.	157	30	NNW.	2 from N.	337	30
S. by E.	1 from S.	168	45	N by W.	1 from N.	348	45
S.	0 from S.	180		N.	0 from N.	360	

example, the U. S. Coast and Geodetic Survey chart of New York Harbor states that in the region of Sandy Hook the variation will be 10° 10′ westerly in 1919, and that its annual increase is 5′. Of course this means that every compass in this region, if uninfluenced by iron in its neighborhood, will point 10° 10′ too far west in 1919, while in 1924 it will be as much as 10°35′ too far west.

If a wooden ship near Sandy Hook were headed North according to her compass, the true course would be 10°10′ to the left of the course shown by her compass or N. 10°10′ W.

Thus, when the error is *westerly*, the true course is always to the *left* of the compass course by the amount of the error, as will be seen in Fig. 2 which illustrates

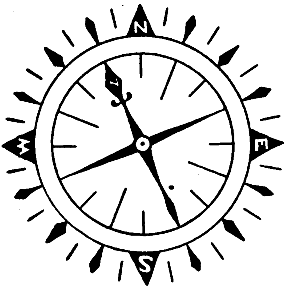


FIGURE 2.

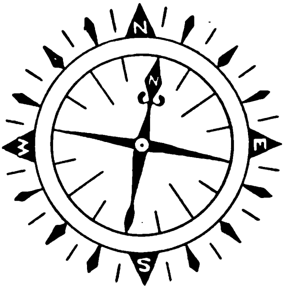


FIGURE 3.

FIGS. 2 and 3.—The outer compass shows true courses, but the inner compass has two points westerly deviation. In Fig. 3, the inner compass has one point easterly deviation.

the condition with two-points westerly compass error. In this case we see that if we imagine ourselves to be standing at the center of the compass and looking outward, the true course is always two points to the *left* of the compass course. Thus if our compass said we were sailing NE., we would really be going NNE.; and if the compass indicated SE., our true course would be ESE.

If we had an error of 10° westerly, the compass courses, and the corresponding true courses, would be as follows:

Compass course			True course	
Referred to the nearest N. or S. point	Expressed in angular measure	Error 10° westerly	Referred to the nearest N. or S. point	Expressed in angular measure
N. 40° E.	40°	Error 10° westerly	N. 30° E.	30°
S. 40° E.	140°	Error 10° westerly	S. 50° E.	130°
S. 40° W.	220°	Error 10° westerly	S. 30° W.	210°
N. 40° W.	320°	Error 10° westerly	N. 50° W.	310°

We see if the error is westerly, we simply *subtract* the amount of the error from the compass course expressed in angular measure; but if the compass course is given in relation to the nearest north or south point, we must be careful to observe what quadrant we are in, taking care that with westerly error the true course is always to the *left* of the compass course.

Westerly variation is met with all over the North Atlantic, with the exception of the Gulf of Mexico and parts of the Caribbean Sea; but easterly variation is characteristic of the North Pacific coasts of America.

Naturally, with *easterly* variation, the true course is always to the right of the compass course by the extent of the error, as is shown in Fig. 3, which represents an *easterly* compass error of one point.

The following rules are now self-evident:

Compass Error Easterly

/ \

True course to the *right* of the compass course.	Compass course to the *left* of the true course.

Compass Error Westerly

/ \

True course to the *left* of the compass course.	Compass course to the *right* of the true course.

Before we can hope to pass as a navigator, we must become thoroughly familiar with these facts, and the only way to accomplish this is by practice, especially at sea; but in default of this, examples such as those given at the end of this chapter will help to make the subject clear.

DEVIATION

Unluckily, however, there is much more to this matter, for modern ships are made of steel, and this becomes magnetized so that on some headings of the ship the effect of the earth's magnetism is more or less counteracted, while on others it is augmented. This complex effect of the ship itself is called *deviation,* and we must determine it for each separate compass course, for if we alter our course, the deviation is apt to change.

Like variation, deviation may be either easterly or westerly; and being in large measure independent of one another the two may tend in opposite directions and thus reduce the error, or they may both tend in the same direction and increase it.

Thus we may distinguish:

I. Compass courses which are simply the reading of the ship's compass uncorrected for variation or deviation.

II. Magnetic courses or compass courses corrected for deviation, but not for variation.

III. True courses, or compass courses corrected for both variation and deviation.

SWINGING SHIP

A practical method for finding the deviation of our compass is to "swing ship" in harbor. In order to do this, we must have an azimuth sight on our compass; and with this we sight on two distant objects on shore which are in line with each other and also with the ship. Suppose these objects bear 295° (N. 65° W.), according to the ship's compass which is affected by both variation and deviation.

Now, in order to get rid of deviation and find the magnetic bearing, carry the compass ashore to the nearer of the two objects, which must, of course, be in a region free from iron; and sight again on the more distant object. Suppose this now bears N. 75° W. As a precaution, sight *back* on the ship, and see if the compass reads as it should S. 75° E.

Evidently the ship's compass has a westerly error of 10° due to deviation, for without deviation, it should have read N. 75° W. when we were on board and sighted on the two objects, but instead of this it read N. 65° W.; and thus the magnetic course is to the left of the compass course, as is always the case with westerly error. If the ship were heading North while we made these observations, we could safely say that if we were sailing North, according to her compass there would be a westerly error of 10° due to the deviation, and her magnetic course would then be N. 10° W., or 350°.

Unfortunately, however, this would be true only when the ship was heading north, for on other headings the deviation would be different. This fact obliges us to swing the ship until she points on a number of headings. We must therefore place the compass back on the ship and take a fresh sight of the shore stations for each new heading. Suppose we decided to test the deviation on ship's headings 20° apart. Our results might appear as in the table on page 21. For the sake of illustration, we have made it out only to 180°, but in practice we should continue it all around the horizon to 360°:

THE NAPIER DIAGRAM

In this case, we have found the deviations for headings 20° apart, but suppose we wished to determine the deviation on the compass course 30°. We know that on 20° the deviation is 0°, and on 40° it is 13° E.; so the deviation for the 30° course is probably about midway between, or 6½° E., but in order to make certain of this, we should construct a Napier Diagram, as in Fig. 4. The vertical axial line is divided into 180 equal parts, each representing a degree. The full, and the dotted lines branch off from this axial line at 20° intervals and make

Ship's heading in angular measure according to the ship's compass	Compass bearing of the shore stations according to the ship's compass in angular measure	Magnetic bearing of the shore stations from the ship	Deviation
0° North	295° (N. 65° W.)	N. 75° W., or 285° angular measure	10° W.
20°	285°	N. 75° W., or 285° angular measure	0°
40°	272°	N. 75° W., or 285° angular measure	13° E.
60°	267°	N. 75° W., or 285° angular measure	18° E.
80°	264°	N. 75° W., or 285° angular measure	21° E.
100°	263°	N. 75° W., or 285° angular measure	22° E.
120°	265°	N. 75° W., or 285° angular measure	20° E.
140°	268°	N. 75° W., or 285° angular measure	17° E.
160°	273°	N. 75° W., of 285° angular measure	12° E.
180°	280°	N. 75° W., or 285° angular measure	5° E.

angles of 60° with it. The dotted lines are divided into parts of the same length as those of the axial line. Taking the compass course from the axial line, we simply lay off

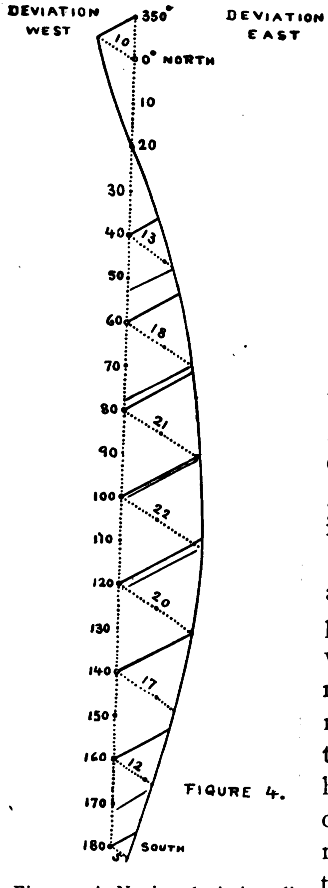


Fig. 4.—A Napier deviation diagram for compass courses from north to south.

the deviation on the dotted cross-line, to the right if easterly and to the left if westerly. Thus if the compass course is north, or 360°, the deviation is 10° W. and thus 10 is laid out on the dotted cross-line to the left. At this point, the dotted cross-line is intersected by a full line and if we follow this full line back to the axial line we find it crosses the axis at 350°; which tells us that if our compass course is N., or 360°, our magnetic course is 350°.

Study of the diagram will also show that if the compass course is 120°, the deviation being 20° E., the magnetic course is 140°; the reason for this is that 60° triangles are equilateral, hence any distance we lay off on the dotted lines must correspond with the same distance on the axial line. One may obtain isometric coördinate paper from dealers to facilitate the plotting of deviation on the Napier diagram.

While deviation has now become the most important of compass errors, due to the almost universal use of steel hulls, it is curious that no one seems to have observed it until the time of Captain Cook's survey of the Barrier reef of Australia in 1769; and Captain Flinders, another great Australian explorer, seems to have been the first to "swing-ship" in 1802.

Unfortunately, deviation changes, even when our course remains the same, if we change our latitude, or as the iron of the ship is heated or cooled, or as the vessel heels in a strong wind, and in new ships, especially, we may expect it to alter in an unexpected manner.

We should, therefore, take azimuth observations of the sun at fairly frequent intervals. The azimuth of the sun is simply its *true* bearing, and is given for every 10 minutes of the day in the Table of Azimuths of the Sun, Publication No. 71 of the U. S. Hydrographic Office.

If we know our local apparent time, we have only to look in this azimuth table under the heading of our latitude and date, or declination of the sun, and the table gives us the corresponding azimuth. For example, on February 13, 1918, off the coast of Delaware, in N. Lat. 38° 11′, W. Long. 74°, with the ship sailing S. by W., the sun bore 153° by the azimuth sight of the ship's compass; at 10 h. 40 min., A.M., local apparent time. What is the deviation?

Looking on page 176 of the Table of Azimuths of the

Sun for N. Lat. 38°, February 13, we find that the true bearing of the sun at 10.40 A.M. is 156°. Our compass read 153°, and thus the total error is 3° E. This 3° of error is, of course, composed of *both* deviation and variation, and looking at the chart we see that the variation is 8°40′ W. Hence the deviation of the compass must be 8°40′ + 3°, or 11°40′ E.

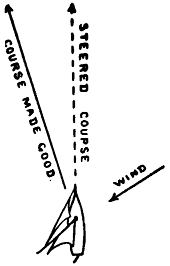


FIGURE 5.

FIG. 5.—Showing that leeway on the starboard tack is equivalent to westerly deviation, because it drives the ship to the left of the steered course.

Leeway is, of course, not a compass error, but we may conveniently consider it as if it were such. For example, if we are close-hauled on the starboard tack, as shown in Fig. 5, the side pressure of the wind on our sails will tend to push us over to the left of the course we are heading upon.

Thus, in Fig. 5, we are headed upon the dotted course but due to leeway we must content ourselves with making the course shown by the full line. We see, then, that leeway on the starboard tack is equivalent to westerly compass error; while leeway on the port tack is analogous to easterly compass error.

A good way in which to determine leeway is to pay a line out aft and observe the angle it makes with the course you are steering.

Let us work out a few examples illustrating the effects of variation, deviation, and leeway. A ship sails the compass course 20° (N. 20° E.) with 6° leeway on the port tack. Variation 11° W., and deviation 8° E. What is the true course?

6° leeway on port tack	6° E.
Deviation	8° E.
Total easterly error	14° E.
Deviation	11° W.
Residual error	3° E.

Answer: True course N. 23° E.

We wish to sail the true course 132° (S. 48° E.). We have 8° leeway on the starboard tack, variation 17° W., and deviation 21° E. What compass course must we steer?

8° leeway starboard tack	8° W.
Variation	17° W.
Total westerly error	25° W.
Deviation	21° E.
Residual error	4° W.

Answer: Compass course 136° (S. 44° E.).

EXAMPLES FOR PRACTICE

1. The compass course being 50°, variation 11° W., deviation 6° E., leeway on starboard tack 4°, what is the true course?
Answer: 41°.

2. The compass course being 120°, deviation 10° E., what is the magnetic course? —*Answer:* 130°.
3. The true course being 195°, variation 6° W., deviation 16° E., what is the compass course? *Answer:* 185°.
4. What are the true courses in the following cases?

Compass Course	Total Error	True Courses
N. 42° E.	8° W.	*Answer:* N. 34° E.
S. 18° E.	8° W.	*Answer:* S. 26° E.
S. 29° W.	8° W.	*Answer:* S. 21° W.
N. 15° W.	8° W.	*Answer:* N. 23° W.

5. Compass course 28°, variation 11° W., deviation 27° E., leeway on starboard tack 6°, what is the true course? —*Answer:* 38°.
6. Compass course S. 54° W., leeway on the port tack 7°, variation 12° W., deviation 16° E., what is the true course? —*Answer:* S. 65° W.
7. A ship desires to sail the true course N. 41° E. The variation is 15° W., deviation 28° E., and she has 8° leeway on the starboard tack. What compass course must she steer? —*Answer:* N. 36° E.
8. The variation being 12° W., deviation 20° E., and the magnetic course 142°, what is the true course, and what is the compass course? —*Answer:* True course, 130°; compass course, 122°.
9. The magnetic bearing of a light house from the ship is 72°, but, according to the ship's compass, it is 86°. What is the deviation? —*Answer:* 14° W.
10. On October 6, 1918, at 9 A.M., in N. Lat. 42°, the azimuth of the sun was 120°, but the ship's compass showed it to be 126°. The local variation was 11° E. What was the deviation? —*Answer:* 17° W.

11. On February 18, 1918, at Key West, Florida, in N. Lat. 24°35′, local apparent time 11h. 20m. A.M., variation 2°22′ E.; the ship's compass read 160°19′, what was the deviation?

—*Answer:* 2°11′ E.

12. The ship is heading on a compass course NE. by N., with a variation of 4° W. At local apparent noon, the compass bearing of the sun is N. 177° E. What is the deviation, and what is the true course?

—*Answer:* Deviation 7° E.; true course 36°45′.

CHAPTER II

DEAD RECKONING

THE great navigators of the fifteenth and sixteenth centuries made their unrivalled discoveries by aid of dead reckoning supplemented only by a laboriously attained and very erroneous determination of latitude, and even to-day despite the invention of the sextant, and the chronometer dead reckoning retains its primary importance in navigation.

If a ship sailed one nautical mile, or 6080 feet, true north or south, she would make a difference of 1′ in her latitude. Difference in latitude may thus be expressed either in nautical miles or in minutes of arc and will be referred to as DL. in the following pages.

Conversely, if a ship sails true east or west, she makes no change in her latitude, but we call the number of nautical miles she has gone her *departure*. One can see that one nautical mile of departure is equivalent to one minute of longitude only on the Equator, but everywhere else a nautical mile is greater than a minute of longitude. Thus on the Equator, departure (Dep.) in nautical miles is equivalent to the same difference in longitude (DLo.), expressed in minutes of arc, but north or south of the Equator, we must know the local ratio between the two in order to convert the one into the other.

Usually, however, a ship sails upon a diagonal course, thus making both difference of latitude and departure.

If we know the angle (θ) her course makes with the meridian and the distance she sails (Dist.), we can easily find the difference of latitude (D.L.) and departure (Dep.) by looking in Table 1 or Table 2, Bowditch. Table 1 is used by sailing vessels, and gives courses down to quarter points, whereas Table 2 is for the use of steamers, and gives courses for each degree.

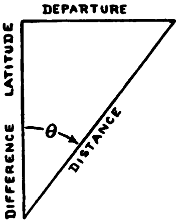


FIG. 6.—Showing a course of $\theta°$ with the distance, difference of latitude, and departure made by the ship.

The use of these traverse tables can best be illustrated by examples: Thus, suppose a ship sails NNE. ¾ E. 41 miles, what difference of latitude and what departure does she make?

On page 525, Bowditch, under the heading for 2¾ point courses, we find that a distance (Dist.) of 41 miles corresponds with a difference of latitude (Lat.) of 35.2 miles and a departure (Dep.) of 21.1 miles. Thus the ship has gone 35.2 miles N., and 21.1 miles E.

A similar use of Table 2, Bowditch, may be illustrated as follows: A ship sails N. 40° E., 280 miles. What difference in latitude and departure does she make?

On page 610, Bowditch, under 40° courses, the distance 280 corresponds with 214.5 DL. and 180 miles Dep.

In these tables, if we take the distance in miles, the difference of latitude and the departure also appear in miles, but as these are simply ratios, if we take any one of them in some other measure, such as inches or yards, the other two will also be given in inches or yards.

A little reflection will show that as the course ranges from 0° (N. or S.) toward 45° (NE., NW., SE., or SW.) the difference of latitude is at first much greater than the departure, but steadily declines; becoming equal to the departure on 45° courses. Also on courses ranging from 45° to 90° (E. or W.) the departure is always greater than the difference of latitude.

It will also be apparent that for complementary course-angles, the difference of latitude and departure is reversed. Thus if on a 30° course the departure is A and the difference of latitude B; on a 60° course the departure will be B and the difference of latitude A. Thus in Tables 1 and 2, Bowditch, we find courses from 0° to 45° at the top of the page, and courses from 45° to 90° at the bottom, with Lat. and Dep. reversed in the columns. We read our Lat. and Dep. *down* from the top and *up* from the bottom of the page.

Example: If a ship sails S. 50° W., 40 miles, what difference of latitude and departure does she make? Looking *up* from the bottom of page 610, Bowditch, for 50° courses, we find DL. 25.7, Dep. 30.6.

Similarly, in Table 1, if the top of the page refers to 2-point courses, the bottom refers to 6-point courses with Lat. and Dep. reversed, as on page 522, Bowditch. In any case, if the difference of latitude is greater than the departure, the course is less than 45°, and if the dif-

ference of latitude is less than the departure, the course is greater than 45° from the meridian line.

Table 1 gives difference of latitude and departure for distances up to 300 miles, and Table 2 up to 600 miles, but we may extend the use of the tables for greater distances as follows:

Example: A ship sails N. 40° E. 894 miles. What difference of latitude and departure does she make? As Table 2 reads only to 600 miles, we divide 894 by 2, giving 447. Then on page 611, Bowditch, distance 447 miles × 2, corresponds with DL. $342.4 \times 2 = 684.8$ and with Dep. $287.3 \times 2 = 574.6$.

Alternative solution: 894 miles = 600 + 294.

Dist. 600	= D.L. 459.6	Dep. 385.7
Dist. 294	= DL. 225.2	Dep. 189
Dist. 894	= DL. 684.8	Dep. 574.7

Dead reckoning courses are *rhumb lines;* that is to say, the course cuts across all meridians at one and the same angle and thus the course is not a straight line but bends upwards toward the pole, as is shown in Fig. 7.

Moreover, the rhumb line is not so short a course as is the great circle, but for distances of not more than 600 miles rhumb-line courses are sufficiently accurate for all purposes of navigation, and are so nearly equal in length to great circle courses that the difference between the two may be neglected; especially as it is practically impossible to steer a truly straight course at sea. In fact, the earth is so large that for the distance traversed by an ordinary ship during the day, we may consider it to be flat and the traverse problems are worked out as if we moved over a plane surface, and are therefore called plane sailings, and Tables 1 and 2, Bowditch, then solve the problems for us with every desirable degree of accuracy.

Indeed, ninety-nine cases out of a hundred in dead

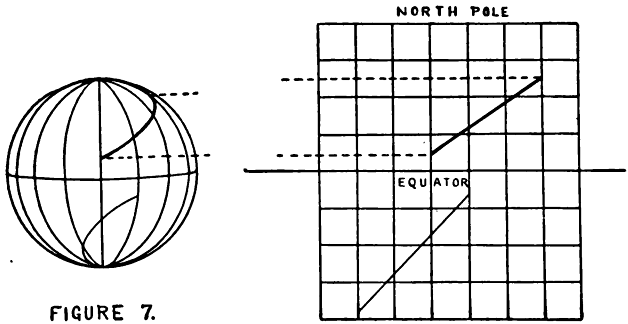


Fig. 7.—A Mercator projection of a hemisphere of the earth, showing that rhumb-line courses, which appear as straight lines on Mercator's chart, are actually curved upward toward the pole.

reckoning are solved on the chart itself with parallel rulers and dividers; miles of distance being taken from the minutes of latitude at the N–S side of the chart. Always use your *chart* whenever you can, for it is only by this means that you can keep in mind the position of all possible dangers near your course, the situation of your nearest harbor of refuge, and how to enter it by day or night.

Obviously, Tables 1 and 2, Bowditch, may be used to find course and distance if difference of latitude and departure are given, or, indeed, any two quantities, if the other two are given. Thus on page 610, Bowditch, if a ship made a difference of latitude of 38.6° and a departure of 46 miles, her course must have been 50°, and her distance 60 miles.

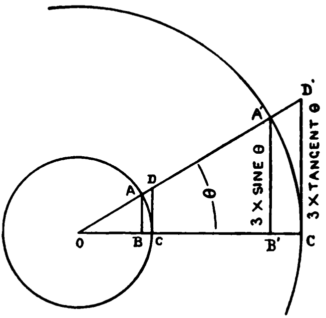


FIGURE 8. FIGURE 9

FIGS. 8 and 9.—In the circle whose radius, OC, is unity; AB is the sine DC the tangent, and OD the secant of the angle θ. The part marked Figure 9 shows a circle whose radius is 3, in which A'B' is 3 × sine θ, D'C' = 3 × tangent θ, and OD' 3 × secant θ.

Or, again, if we knew that a ship had made a distance of 20 miles, with a departure of 5.8 miles, we would find on page 520 of Table 1, Bowditch, that she must have sailed upon a 1½ point course, and have made 19.1 miles in difference of latitude.

In using these tables, it is well to look up the larger of the two numbers, and "fit" the smaller to it as closely as we can.

Thus we might have a DL. of 430, and a Dep. 361, and in this case the best "fit" would be DL. 429.8 to Dep. 360.6, found on page 611, Bowditch; the corresponding course and distance being 40° and 561 miles.

Having now learned something of the method of using the traverse tables, we will pause a moment to see how they have been made.

In order to understand this, we must know something about trigonometry: If we had a circle whose radius OC,

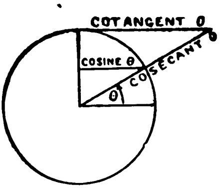


FIGURE 10.

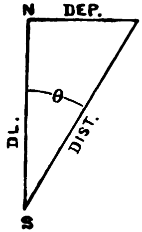


FIGURE 11.

FIG. 10.—Cosine, cotangent and cosecant of the angle.

FIG. 11.—Illustrating the relations between distance, departure, and difference of latitude with reference to the course of the ship θ.

Fig. 8, is unity, AB is called the sine of any angle such as θ. OB is the cosine, DC is the tangent, and OD the secant of the angle θ. Of course, the larger the radius of the circle the longer all these distances AB, OB, DC, etc., would become. For example, if, as in Fig. 9, the radius OC were 3 instead of 1, AB would become $3 \times$ sine θ, and DC would then be $3 \times$ tangent θ, etc.

The sine of $90°-\theta$ is called the *co*-sine of θ, and so with the tangent and secant, as is shown in Fig. 10.

One should gain a clear idea of these matters, for they are of vital importance in many problems in navigation.

Now let us see how these things apply to dead reckoning.

In Fig. 11, imagine the ship to sail a certain distance (Dist.) on a course θ which in this case we have represented as making an angle of 30° with the meridian SN. She would then have gone northward by a difference of latitude represented by the line SN; and eastward on a departure represented by the line DEP. Considering the distance as a radius, we see that:

1. $\text{DEP.} = \text{Dist. sine } \theta.$
2. $\text{DL.} = \text{cosine } \theta.$
3. $\text{DIST.} = \dfrac{\text{DL.}}{\text{cosine } \theta.} = \text{DL. secant } \theta.$
4. $\text{tangent } \theta = \dfrac{\text{DEP.}}{\text{DL.}}$, or $\text{DEP.} = \text{DL. tangent } \theta.$

The traverse Tables 1 and 2 in Bowditch have been calculated from these formulæ, and while we can use the tables without knowing how they have been constructed, our knowledge will be *real* and *lasting* only if we grasp the underlying principles.

Instead of looking up departure, distance, etc., directly in the tables we could look up the sines, secants, etc., of the course in Table 41, Bowditch, which gives the lengths of these functions, in a circle whose radius is unity. Thus, suppose our ship sailed 50 miles on a course N. 40° E., what difference of latitude and what departure would she make?

Turning to page 752, Table 41, Bowditch, we find the sine of 30° to be 0.5 and the cosine 0.86603. Therefore,

$$\text{DL.} = \text{Dist. cosine } \theta = 50 \times 0.866 = 43.3 \text{ miles, and}$$
$$\text{Dep.} = \text{Dist. sine } \theta = 50 \times 0.5 = 25 \text{ miles.}$$

Instead of using natural sines, cosines, etc., we might have used logarithms; and these are always more convenient where the numbers are large, or where many numbers are to be multiplied together; for in order to multiply a series of numbers, we merely *add* their logarithms.

The logarithm of any number is simply the exponent to which 10 must be raised to equal that number. Thus the logarithm of 10 is 1, because $10^1 = 10$, the logarithm the logarithm of $1000 = (10 \times 10 \times 10)$ is 3, and that of of 100 is 2 because $10^2 = (10 \times 10) = 100$. Similarly, 10,000 is 4, etc.

If we are familiar with algebra, we will also see that the logarithm of 1 is 0, that of 0.1 is −1, and the logarithm of 0.01 is −2, etc.

Suppose, however, we had to find the logarithm of 824. We know that this logarithm must be more than 2 because the number is greater than 100. Also it must be less than 3 because the number is less than 1000. Therefore, it must be 2 *and* a fraction. The *fractional part,* or mantissa, is shown on page 768, Table 42, Bowditch, opposite 824, where we find 91593. Therefore the logarithm we require is 2.91593.

Suppose we wished to find the logarithm of 0.866. Here we know the logarithm must be less than 0, for the number is less than 1, and the logarithm of 1 is 0. Also it is not so low as –2, for the logarithm of 0.01 is –2. It must, therefore, be –1 *and* a fraction. Turning to page 768, Table 42, Bowditch, we find, opposite 866, the fractional part of the logarithm to be 93752. The entire logarithm is therefore –1.93752.

Now suppose we wished to multiply 50 by 0.866. Using logarithms, we proceed as follows:

The logarithm of 50	=	1.69897
The logarithm of 0.866	=	–1.93752
The logarithm of 50 × 0.866	=	1.63649

Now turning to page 761, Bowditch, we find 63649 corresponds with 433, and as the characteristic of our logarithm is 1, the number corresponding with it must be more than 10 and less than 100, or 43.3.

For the sake of convenience and in order to avoid writing negative characteristics, we may add 10 to each characteristic, and then subtract it at the end of the logarithm. Thus 1.69897 becomes 11.69897 –10, while –1.93752 becomes 9.93752 –10.

The logarithms in Tables 44 and 45, Bowditch, are so stated, but the –10 is left out to save space, although one should remember that it should be there. One will easily understand that if when we *multiply* numbers we *add* their logarithms, we must *subtract* their logarithms if we *divide* one number by the other. Also, if we raise numbers to the square, cube, etc., we must multiply their logarithms by 2, 3, etc.

There are many more important facts respecting logarithms, but what we have now said will suffice to enable us to solve the problems we will meet with in navigation; but as we will make constant use of logarithms, one should master the little we have said before proceeding. Indeed, in this entire subject of navigation, one part depends so intimately upon another that if we fail to understand anything, we soon find ourselves floundering badly, so be on guard not to let anything in this book escape you, for it will not be repeated.

Now, to return to the subject of dead reckoning: We are usually more interested in knowing the difference of longitude we have made in sailing east or west than in knowing the number of miles in departure. It is therefore necessary to find a relation between difference of longitude in minutes of arc, and the corresponding departure in miles, so we can convert the one into the other in any latitude. Of course, on the Equator, miles of departure are the same as minutes of longitude, but the farther we go northward or southward the shorter the departure corresponding to a minute of arc in longitude.

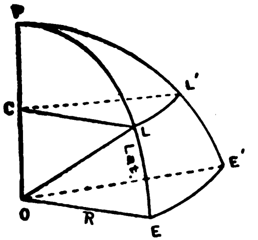


FIGURE 12.

FIG. 12.—Illustrating the relation between departure in miles and difference of longitude in minutes of arc.

Let Fig. 12 represent a perspective view of the northern half of a sector of the earth, wherein P is the North Pole, O the center of the earth, OP the half-axis of the earth, OE the radius (R) of the earth, and EE′ an arc along the Equator.

Now suppose we sailed due east along the arc LL′ in latitude (Lat.) north of the Equator.

From the point L drop a perpendicular LC to the axis of the earth. Then LC = radius of earth × cosine of the latitude = R × cos. Lat. By geometry, as the lengths of the arcs LL′ and EE′ are proportional to their radii,

$$\frac{LL'}{EE'} = \frac{LC}{OE} = \frac{\text{Radius of earth} \times \text{cosine lat.}}{\text{Radius of earth}} = \text{cosine lat.}$$

Now, LL′ in *miles* is the departure we have sailed, while EE′ in *minutes of arc* is the difference in longitude we have made. Calling the latter by the symbol DLo., we have:

$$\frac{\text{Dep.}}{\text{DLo.}} = \text{cosine of the latitude of the ship.}$$

$$\text{or} \quad \text{Dep.} = \text{DLo. cosine Lat.}$$

$$\text{and DLo.} = \frac{\text{Dep.}}{\text{cosine Lat.}} = \text{Dep. secant Lat.}$$

Now, in discussing the mode of construction of the traverse Tables 1 and 2, Bowditch, we found that DL. = Dist. × cosine of the course-angle, and Dist. = DL. × secant of the course-angle.

Making proportions between our equations, we find

DLo. : Dist. = Dept. secant Lat. : DL. secant course, and
Dep. : DL. = DLo. cosine Lat. : Dist. cosine course.

Hence the

RULE

CASE I.—To convert difference of longitude (DLo.) into departure: Call the latitude of the ship the "course." Then, in Table 1, or 2, Bowditch, enter Dist. column with DLo. and find the corresponding departure in the "Lat." column.

CASE II.—To convert departure into difference of longitude: Call the latitude of the ship the "course." Then, in Table 1, or 2, Bowditch, enter "Lat." column with the departure, and find difference of longitude in the corresponding Dist. column.

In other words, you look up "longitude" (DLo.) in the Distance column, and you can remember this from the catch word "Long distance."

Much of this may seem both tedious and complex, but one or two examples and a little practical experience will soon make you familiar with it, and show you how easily it is applied.

Thus to illustrate Case I, suppose a ship left N. Lat. 40° 15′, W. Long. 64° 28′ and sailed into N. Lat. 40° 25′ 42″, W. Long. 67° 48′. What course, distance, difference of latitude, and departure did she make?

Lat. in	40° 25′ 42″ N.	Long. in	67° 48′ W.
Lat. left	40° 15′ 00″ N.	Long. left	64° 28′ W.
DL.	10′ 42″ N.	DLo.	3° 20′ W.
DL. = 10.7 miles.		DLo. = 200′.	

Given DLo. 200′ to Find Departure:

Take Lat. of ship, 40°, as the "course."

On page 610, Bowditch, enter Dist. column with DLo. 200, and in the corresponding "Lat." column find 153.2, which is the departure we seek.

Now knowing departure to be 153.2 miles and the difference of latitude 10.7 miles, we find a fair "fit" on page 538, Table 2, Bowditch, which shows the course of the ship was N. 86° W., and the distance about 154 miles.

As an illustration of Case II: A vessel leaves N. Lat. 50°14′, W. Long. 45°28′, and sails N. 40° E., 30 miles. What latitude and longitude has he arrived at?

On page 610, Bowditch, a course of 40° with Dist. 30 miles gives DL. 23 miles and Dep. 19.3 miles.

Given the Departure to Find the Corresponding Difference of Longitude:

Take the latitude of the ship, 50°, as the "course."

Enter the "Lat." column on page 610, Bowditch, with the departure 19.3 miles, and in the "Dist." column find 30′, which is the difference of longitude we seek. Then:

	Lat. left	50°14′ N.	Long. left	45°28′ W.
	DL.	23′ N.	DLo.	30′ E.
Ans.:	Lat. in	50°37′ N.	Long. in	44°58′ W.

In the two examples we have just cited, the ship made so slight a change in her latitude that we were justified in assuming that the vessel sailed all the time on one and the same parallel of latitude.

MIDDLE LATITUDE SAILING

Suppose, however, the ship sailed on a diagonal course from say N. Lat. 0° to N. Lat. 30°, as in Fig. 13, evidently her average, or *middle latitude*, would be 15°, and in working out the average relation between her departure and difference of longitude, we may assume that she sailed all the time on the parallel of 15°. For long distances, this supposition is not quite accurate, but we may then apply a correction given in a table on page 77 of Bowditch.

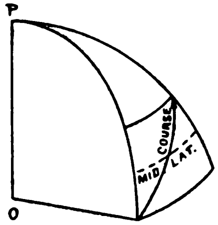


FIGURE 13.

FIG. 13.—Showing that the middle latitude course gives the mean departure and difference of longitude.

Let us illustrate middle latitude sailing by an example: A ship leaves N. Lat. 37°15′, W. Long. 75°; and sails into N. Lat. 43°29′, W. Long. 67°40′. What was her course, distance, difference of latitude and departure?

Lat. in	43°29′ N.	Long. in	67°40′ W.
Lat. left	37°15′ N.	Long. left	75° W.
Difference of Lat.	6°14′ N.	DLo.	440′ E.
DL.	374 miles N.	Diff. of Long.	7°20′ E.

Lat. in	43°29′ N.	Correction for difference of latitude 6°, middle latitude 40° from page 77 Bowditch −12′.
Lat. left	37°15′ N.	
	2) 80°44′	
Mid. Lat.	40°22′	
	−12′	
Corrected Middle latitude	40°10′ =	40°.

We take 40° as the middle latitude because this is the nearest whole degree of latitude. Thus had the corrected middle latitude been 40°35′ we would have taken 41° as our middle latitude.

On page 611, Bowditch, take the "course" as the middle latitude 40°. Then enter "distance" column DLo. 440, and in "Lat." column find 337.1 miles which is the departure we seek.

Now with DL. 374, and Dep. 337.1 we find a fair "fit" on page 615, Bowditch, with a course of N. 42° E., and distance 503 miles.

The answer is, therefore, course N. 42° E., distance 503 miles, difference of latitude 374 miles, and departure 337 miles.

Middle latitude sailing gives a good result in all problems of sailing from the Equator to about 60° N. or S. latitude, but for the Arctic and Antarctic, and for courses which cross the Equator, one had better employ "Mercator Sailing." If you use middle latitude for courses which cross the Equator, estimate the northern and southern parts of the course separately.

MERCATOR SAILING

In the Mercator chart, the earth is supposed to be a cylinder and is unrolled and laid out flat, so that the meridians instead of meeting at the poles, as they should are represented as parallel lines always keeping the same distance apart that they have at the Equator. Thus the parallels between meridians on the Mercator chart are too wide as we go north or south from the Equator, and the farther we go from the Equator the more "spread out" the chart appears, so that it is quite misleading for the polar regions. Also on the Mercator chart not only are the parallels widened as we go north or south from the Equator, but the meridians must also be correspondingly lengthened, as shown in Fig. 7, so that a rhumb line drawn on the chart will appear as a straight line. These lengths by which the meridians are extended in each latitude are called meridional parts or increased latitudes and are given in minutes of arc in Table 3, pages 621–628, Bowditch.

In working problems by Mercator sailing, if both the latitude you have left and the latitude you are in are north or south of the Equator, subtract the lesser meridional part from the greater, but if one latitude is north and the other south of the Equator, add them. Mercator sailing is especially convenient for finding the course.

Two cases in Mercator sailing may make the matter clear:

CASE I.—Crossing the Equator. What is the course and distance from Brava Island Light House, Cape Verde Islands in N. Lat. 14°50′30″ W. Long. 24°40′ to Ascension Island S. Lat. 7°55′20″, W. Long. 14°28′?

SOLUTION BY MERCATOR SAILING

Lat. left	N. 14°50′30″	Long. left	W. 24°40′
Lat. in	S. 7°55′20″	Long. in	W. 14°28′
Diff. of Lat.	22°45′50″	Difference of Long.	10°12′
DL.	1366 miles	DLo.	612′

Meridional Parts, pp. 621, 622:

Table 3, Bowditch, for N. Lat. $14°50'30''$	$= +894.7'$
Meridional parts for S. Lat. $7°55'20''$	$= +473.6'$
Meridional difference of Latitude	$= M$ Lat. $1368.3'$

Looking up *M*. Lat., 1368, in the "Lat." column and DLo., 612, in the "Dep." column of Table 2, Bowditch, we find on page 579, that M. Lat. 342×4 in "Lat." column; and DLo. 153×4 in "Dep." column corresponds with a course of S. 24° E.

Then on page 578, Table 2, Bowditch, under 24° courses, a difference of latitude of 1366 miles $= 136.6 \times 10$, corresponds to a distance of $149.5 \times 10 = 1495$ miles.

Case II.—Mercator sailing in the Arctic regions: A ship sails N. 40° E., 294 miles from North Cape, Norway, N. Lat. 71°11′, E. Long. 25°40′. What latitude and longitude has she arrived at?

On page 610, Bowditch, a course of 40°, and distance 294 miles, corresponds with a difference of latitude of 225.2 miles $= 3°45'12''$. Hence the latitude arrived at is N. $71°11' + 3°45'12'' =$ N. $74°56'12''$.

The Meridional parts of N. $74°56'$	$= +6932.3'$
The Meridional parts of N. $71°11'$	$= -6157.5'$
Meridional Latitude difference, *M*. Lat.	$= 774.8'$

On page 61, Bowditch, under 40° courses, and *M*. Lat., $774.8' = (387.4 \times 2)'$; find difference of longitude in "Departure" column of $325' \times 2 = 650' = 10°50'$.

Hence E. Long. $25°40' + 10°50' =$ E. Long. $36°30'$. The vessel has thus arrived at N. Lat. $74°56'$ E. Long. $36°30'$.

TRAVERSE SAILING

Often a ship sails upon a zig-zag course. In this case, look up the difference of latitude, and the departure for each separate course. Then add all the northerly and all the southerly differences of latitude, and subtract the lesser sum from the greater. Similarly, add all the easterly and all the westerly departures and subtract the lesser from the greater; and the result will be the difference of latitude and departure the ship has made.

In this connection, currents may be regarded as courses; the ship moving in the direction and at the rate of the current.

If, however, we wish to find how we must steer to *overcome* the effect of a current, reverse the direction of the current and consider it as a course. We will give an illustration of this in crossing the Gulf Stream.

The method for working a traverse on a zig-zag course is illustrated in the following example:

A ship takes departure with Navesink Highlands Light House (N. Lat. $40°23'48''$, W. Long. $73°59'10''$) bearing N. 60° W., 5 miles, true. She then sails the following true courses: N. 30° E., 14 miles. On this course there was a tidal current of ½ knot per hour for 4 hours, setting to S.E. The ship then sails the following courses: S. 20° E. 11 miles, N. 60° W. 16 miles. What is her difference of latitude, and her departure from Navesink Highlands Light House?

True courses	Distance in miles	Difference of latitude		Departure	
		N.	S.	E.	W.
S. 60° E.	5	....	2.5	4.3	....
N. 30° E.	14	12.1	....	7	....
S. 45° E.	2	....	1.4	1.4	....
Current S. 20° E.	11	....	10.3	3.8	....
N. 60° W.	16	8	....	....	13.9
		20.1	14.2	16.5	13.9
		14.2		13.9	
		5.9		2.6	

Ans:—5.9 miles difference of latitude, 2.6 miles departure. The ship is about to enter Ambrose Channel, New York Harbor.

ALLOWANCE FOR CURRENTS IN MAKING COURSES

The true course and distance from Cape Florida bell buoy to Gun Cay Entrance, Bahamas, is S. 85° E., distance 45 miles; but the current of the Gulf Stream sets northward along the entire distance at an average rate of 3 knots per hour. What course must be steered to offset this current by a vessel making 9 knots per hour?

At 9 knots per hour 45 miles is covered in 5 hours. The vessel will thus be carried $5 \times 3 = 15$ miles northward by the current, and thus, to offset the current, we must sail 15 miles south. Thus the course to be steered worked out by dead reckoning is as follows:

True courses	Distance in miles	Latitude N.	Latitude S.	Departure E.	Departure W.
S. 85° E.	45	..	3.9	44.8	..
Curr'nt *reversed* S	15	..	15	0	..
			18.9	44.8	

On page 576, Table 2, Bowditch, we find a departure of 44.8. Difference of latitude of 18.9 corresponds with a course S. 67° E., and this is the course we must steer.

GREAT CIRCLE SAILING

The rhumb-line course which we have met with in all these problems of dead reckoning is not the shortest distance between two points on the earth, for the rhumb line, although it appears as a straight line on Mercator charts, is in reality curved upward toward the pole, for as the meridians converge, it cuts each successive one at one and the same angle, as is shown in Fig. 7, page 32.

The shortest distance is given, however, by the great circle; this being the circle whose center is at the center of the earth and whose plane passes through the two points, and the earth's center. If we sail on this course our bow always points straight towards our port of destination.

If, however, our ports of departure and of destination lie within 30° of the Equator, there is practically no advantage in sailing a great-circle course; and even on courses in fairly high latitudes, there is but little saving.

Thus the great-circle distance from south of the Great Banks of Newfoundland to the mouth of the English Channel is 1784 miles, and the rhumb-line course is only 13 miles farther; yet the farther the course as a whole lies from the Equator, the greater the saving on a great-circle course. Of course, in following a great circle, we really sail upon a series of straight lines which gradually change direction, following the curve of the course. If, however, you are blown off the great circle, do not attempt to get back upon it, but construct a new great circle from your present position to the port of destination.

Very often, currents, obstacles, etc., are far more important in determining courses than are actual distances. Thus steamers in voyaging between New York and Key West, Florida, keep close in along the coast on the way down where they enjoy the benefit of the shore current which drifts slowly southward; but in coming north they go far out into the Gulf Stream to Cape Hatteras, gaining thereby about 70 miles each day due to the strong current.

To calculate a great-circle course is a complex problem in spherical trigonometry, but we can avoid this trouble by getting a great circle chart upon which all straight lines are great circles. Then draw a straight line from your port of departure to your port of destination, see where it cuts each meridian and transfer it to your Mercator chart.

Another good way we owe to Sir George Airy (Fig. 14). Connect the two places on a Mercator chart by a straight line. Then from its middle point drop a perpendicular southward in the northern hemisphere until it cuts a certain parallel dependent upon the latitude of the middle point. This parallel is given in a table on page 82, Bowditch. Now draw a circle with this point as a center, passing through your port of departure and your

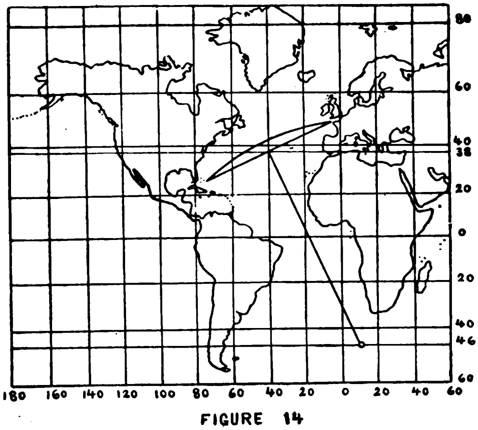


FIG. 14.—Airy's method for drawing a great circle course on a Mercator chart. The course is from the Bahamas in N. Lat. 26° to the English Channel, N. Lat. 50°. The middle latitude is N. 38° and the "corresponding parallel" S. 46°.

destination and the curve is very nearly the great circle you desire.

EXAMPLES FOR PRACTICE IN DEAD RECKONING

1. A ship sails 54 miles on the true course N. 38° E., what difference of latitude, and what departure does she make? —*Answer:* DL. 42.6 miles; Dep. 33.2 miles.

2. A ship sailing in a northerly and westerly direction makes a difference of latitude of 258 miles and a departure of 154.8 miles, what was her course and distance?
—*Answer:* Course N. 31° W.; Distance 301 miles.

3. A ship sails 73 miles on the true course S. 65° W., what difference of latitude and what departure does she make?
—*Answer:* DL. 30.9; Dep. 66.2.

4. A ship makes a departure of 1460 miles on a true course S. 65° E., what difference of latitude and what distance does she make?
—*Answer:* DL. 680; Distance 1610 miles.

5. A ship in N. Lat. 40°10′, W. Long. 62°14′, sails the true course N. 41° E. and makes a difference of latitude on this course of 287 miles. What departure and what distance does she make, and what latitude and longitude has she arrived at?
—*Answer:* Dep. 250; Dist. 380; Lat. N. 44° 57′; Long. W. 56°38′.

6. A steam fisherman takes departure with Nantucket Shoals Lightship (N. Lat. 40°37′, W. Long. 69°37′), bearing N. 40° W., true, 6 miles from the steamer. She then steams upon the following true courses: S. 81° E., 92 miles; N. 54° W., 58 miles; S. 27° W., 75 miles. She has also encountered a current moving N. 45° E. at the rate of one mile per hour for 6 hours. What latitude and longitude has she arrived at, and what course and distance has she made from the Lightship?
—*Answer:* N. Lat. 39°49′30″; W. Long. 69°13′; Course S. 21° E.; Distance 51 miles.

7. A ship taking departure from 6 miles ESE. of Frying Pan Shoals Lightship, coast of North Carolina (N. Lat. 33°34′-26″, W. Long. 77°49′12″) desires to sail S. 40° E., true, for 90 miles at the rate of 9 miles per hour across the Gulf Stream which here makes an average rate of 1.5 miles N.E.

per hour. What course must she steer in order to make the actual course S. 40° E.? And what latitude and longitude will she arrive at?

—*Answer:* Course S. 31° E.; N. Lat. 32°12'38"; W. Long. 76°45'54".

8. What is the course and distance by Mercator sailing from Shark Point, mouth of the Congo River, S. Lat. 6°04'36"; E. Long. 12°15'; to Cape Three Points Lighthouse, N. Lat. 4°45', W. Long. 2°05'45"?

—*Answer:* Course N. 53° W.; Distance 1078 miles.

9. What is the course by Mercator, and the distance by Middle Latitude sailing from Scotland Lightship, mouth of New York Harbor, N. Lat. 40°26'30", W. Long. 73°55' to Frying Pan Shoals Lightship, North Carolina, N. Lat. 33°34'26"; W. Long. 77°49'12"?

—*Answer:* Course S. 24½° W.; distance 452 miles.

10 What is the course and distance from the SE. coast of Greenland N. Lat. 70°, W. Long. 20° to the NW. coast of Spitzbergen N. Lat. 80°, W. Long. 10°?

—*Answer:* By Mercator sailing: Course N. 14° E., distance 618 miles. By Middle Latitude sailing: Course N. 14½ E., distance 620 miles. The Mercator solution is to be preferred for high latitudes.

CHAPTER III

PILOTING

ALMOST anyone can plunge along over the wide and open sea, but the true test of a navigator comes when he approaches the coast, enters his harbor, or makes his dock.

In the first place, you can hardly know too much about the chart. Refer to it constantly. Work out your courses by graphic methods, using dividers and parallel rulers. Always refer your soundings to the chart, and when near a coast, keep your position constantly in mind.

In case of fog, or when in doubt respecting your position, take a series of soundings at regular intervals and lay them out to scale with the chart on a piece of transparent paper, and then fit this with the soundings shown on the chart. You will find there is just one course upon which your plotted soundings accord with those shown on the chart, and this is where you are. This simple method will indicate your position as accurately as can any astronomical sight, and many a ship has been saved through its use, and many a one lost through neglect to follow it.

For example: Suppose a ship to be in a dense fog and flat calm such that bell- and whistling-buoys are not rolling. She has only soundings to guide her. She sails NW. ¼ N., magnetic, toward New York harbor at the rate of 3 miles per hour and takes soundings every 10 minutes, or a half-mile apart. The soundings in feet are as follows, the tide being 4 feet high: 41, 24, 25, 26, 14, 19, 16, 14, 14, 30, 44.

If you lay these figures out on a piece of transparent paper, you will find that the only position in which they will accord with the soundings shown on the U. S. Coast Survey chart No. 369, is on a course from just south of the red bell-buoy 2A at the mouth of Ambrose Channel, toward Swinburne Island; and this being the case the

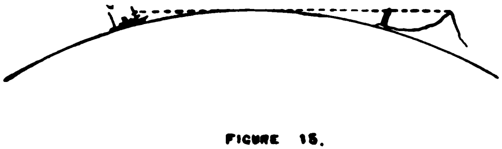


FIG. 15.—Diagram illustrating visibility of objects at sea.

final sounding of 44 feet was a positive indication that the ship had come into the inner end of Ambrose Channel and that her course should then be changed to N. by W., true, to enter New York Harbor.

TIME OF HIGH AND LOW TIDE

Soundings on charts are given for mean low tide, so it becomes important to know whether the tide is high or low when we approach a shore; and this is especially true along the New England coast, where the tide in most places ranges from about 10 to 15 feet north of Cape Cod, reaching 50 feet in the Bay of Fundy. From New York southward, the tides are not so important, ranging from about 5 to 7 feet in most places between Cape Canaveral, Florida, and Sandy Hook.

It is well, however, to consult the tide tables, for there are many local peculiarities in time and range of tides; but if you have no tide table, you can easily calculate the time of high or low tide with a fair degree of approximation.

High tide at each place comes at a certain average time *after* the moon has passed the meridian of that place, and this lag of the tide behind the moon is called the lunitidal interval, and is given in Appendix IV, pp. 279–380, Bowditch, for many places all over the earth.

For example: What was the time of high and low tide off Sandy Hook, mouth of New York Harbor, on August 10, 1918?

If we look on page 77 of the American Nautical Almanac for 1918, we find that the moon was on the meridian at Greenwich, England, at 2.37 P.M. on August 10; and that on August 11, it came to the meridian 41 minutes later, or at 3.18 P.M. Now Sandy Hook is in West Longitude 74°, or about $^1/_5$ the way around the earth from Greenwich, so as the moon loses 41 minutes in the time of one rotation of the earth, it will lose about 8 minutes in about $^1/_5$ of this rotation. Hence the moon was on the meridian at Sandy Hook about 2.45 P.M. or 8 minutes later by local time than it was when over Greenwich. Table II, Bowditch, is intended for use in calculations such as this.

Now, on page 283, Bowditch, we find the lunitidal interval for high water is 7 h. 30 m. and for low water 1 h. 23 m. at Sandy Hook.

Thus high tide comes at 2 h. 45 m. + 7 h. 30 m. or 10.15 P.M.; and low tide at 2 h. 45 m. + 1 h. 23 m., or 4.08 P.M. As everyone knows, the ocean tides follow one another at intervals of about 12½ hours, so the previous high tide at Sandy Hook came about 9.45 A.M., August 10. These calculations are only approximate, for the true times of high tide at Sandy Hook on August 10, 1918, were 9.49 A.M. and 10.03 P.M.

Soundings are commonly made with the lead line. The lead is usually 10 to 30 pounds in weight, and there is a hollow at its end to hold tallow to which a sample of the bottom may adhere. The line is marked at distances from the lead as follows:

2 fathoms, 2 strips of leather.
3 fathoms, 3 strips of leather.
5 fathoms, a white rag.
7 fathoms, a red rag.
10 fathoms, a piece of leather with a hole in it.
13 fathoms, same as at 3 fathoms.
15 fathoms, same as at 5 fathoms.
17 fathoms, same as at 7 fathoms.
20 fathoms, with 2 knots.

The Lord Kelvin sounding machine is, however, more accurate than the lead line, and soundings may be taken with it when the ship is going at full speed. It consists of a reel holding a fine wire. At the end of the wire there is a lead, and above this a case holding a slender glass tube the lower end of which is open and the upper end sealed. This tube contains a colored substance which when wet changes color as the pressure causes the water to rise in the tube. Of course, the deeper the water the greater the pressure, and one has only to place the tube against a properly made scale and read off the depth.

It is important to know the speed of your vessel, and one of the best ways in which to determine this is to standardize the revolutions of the propeller with reference to your rate of speed. Ordinarily, however, one uses some form of the taffrail log, which is a small propeller-shaped spinner attached to the end of a long braided line. The twisting of this line turns the dial-hands of an indicator which enables us to read the speed in knots, a knot being the unit of rate, or one nautical mile per hour. Table 33, page 732, Bowditch, gives the speed in knots per hour developed by a vessel traversing a nautical mile in any given number of minutes and seconds.

Cultivate the habit of estimating distances at sea. Your horizon is much nearer than the novice imagines it to be, and its distance in nautical miles is given approximately by the formula:

$$1.1 \sqrt{\text{Height of eye in feet}}$$

Thus if your eye is 25 feet above sea level, the horizon is distant $1.1\sqrt{25} = 6.05$ miles. Table 6, p. 640, Bowditch, gives the distance of visibility of objects of various heights up to 10,000 feet.

A practical form of this problem is to tell how far you can see a lighthouse.

For example: Suppose your eye to be 36 feet above sea level, how far can you see the top of a lighthouse 100 feet high? The distance in nautical miles is given by the formula

$$1.1\,(\sqrt{36} + \sqrt{100} = 17.6 \text{ nautical miles.}$$

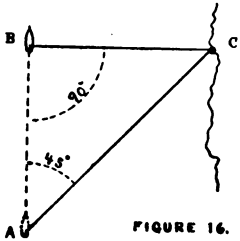
As a matter of fact, however, you cannot depend upon sighting a lighthouse, especially by day, until some part of it lifts above the horizon, and in the problem above, you will find $\sqrt{36} + \sqrt{100} = 16$ miles nearer the truth than is 17.6; although at night one can sometimes see the glare of a light even before any part of it lifts above the horizon.

Remember that when the white beach becomes visible, or you can just see the foam along the sides of a passing vessel, these objects are within $\sqrt{\text{Height of your eye in feet}}$ from you in nautical miles.

If you know your speed, you can easily tell the distance at which you pass any stationary object. One of the best ways in which to accomplish this is by the "bow and beam" method. Observe the log when the object bears 45° off your course, as at A, Fig. 16, then read the log again when the object bears 90° (abeam) to your course as at B. Then the distance AB = BC is the distance of the object when you are at B.

For example: A ship sailing N. by E. observes that the log reads 30.1 knots when a lighthouse bears NE. by E. When the light bore E. by S., the log read 42.2 knots. Its distance was then 42.2 – 30.1 = 12.1 miles.

Another form of this problem is that of "doubling the angle on the bow," the first bearing being, say 30°



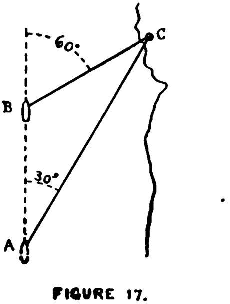


FIG. 16.—A "bow and beam" bearing. Ab = BC.
FIG. 17.—"Doubling the angle of the bow." AB = BC.

and the second 60°, as in Fig. 17. Then AB = BC, the triangle being isoceles.

The 26½°–45° bearing is of use when we wish to know how far off some point we *will* be when we reach it. In this case, we may take the first bearing at 26½° and the second at 45°, as in Fig. 18, and then the distance we have sailed *between* bearings will be the same as the distance we *will be* off the point, when we pass it abeam.

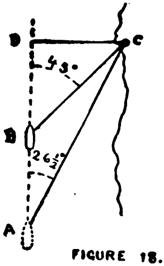


FIG. 18.—A 26½°–45° bearing, in which case AB = DC.

In any case, Table 5B, Bowditch, tells us how far we are from any point and how far off we *will be* when it bears abeam for any two bearings.

For example: A ship sails N. 20° E. She sights a lighthouse bearing N. 40° E., and then after sailing 3 miles the same lighthouse bears N. 54° E. (1) How far is the lighthouse from the ship at the time of taking the second bearing, and (2) how far will the ship be from the lighthouse when it bears abeam?

Course N. 20° E. = 20° course

First bearing N. 40° E......	Difference between course and first bearing 20°.
Second bearing N. 54° E....	Difference between course and second bearing 34°.

Table 5B, page 634, Bowditch, gives the factors 1.41 for the distance at time of second bearing, and 0.79 for the distance from the lighthouse when passing abeam. Then:

3 miles × 1.41 = 4.23 miles = Distance of the lighthouse when sighted at the time of the second bearing, and

3 miles × 0.79 = 2.37 miles when passing abeam.

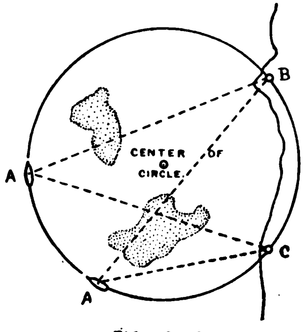


FIGURE 19.

FIG. 19.—Horizontal danger angle. Keep the angle between B–C and the ship less than BAC, and the ship will be outside the circle of danger.

In order to avoid offshore reefs, it is often desirable to draw a "danger angle" diagram upon the chart, as is shown in Fig. 19.

Select two prominent shore objects shown on the chart and connect them by a straight line. Then, from the middle of this line, drop a perpendicular and somewhere on this perpendicular you will find the center of a circle which will pass through the two shore stations and also *outside* of the danger, such as the shoals in Fig. 19. Now, with a protractor, measure the angle BAC, and set your sextant to it. Then watch the two objects B and C, and as long as the angle they make with the ship is *less* than BAC you are outside of the circle and therefore safe.

Vertical danger angles are rarely used, for being usually very small they are difficult to measure accurately unless you have a range finder. For example, if the lighthouse in Fig. 20 is h. feet high, and its top makes

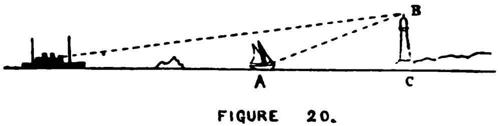


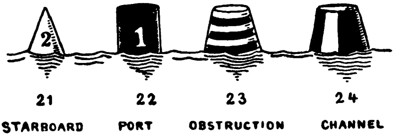
Fig. 20.—Vertical danger angle.

an angle θ with the horizon, then the distance AC in miles $= \dfrac{\textit{Cotangent } \theta \times h \textit{ in feet,}}{6080}$ there being approximately 6080 feet in a nautical mile.

Table 33, pp. 729–730, Bowditch, gives the distances up to 5 nautical miles corresponding to various angles for vertical objects ranging from 40 to 2000 feet in height; but most of these angles are so small that the error in measuring them at sea may be considerable.

When entering harbors, keep a sharp lookout for the buoys, but never conclude that the first buoy you see is the one you are seeking until you verify its position upon the chart in relation to all other buoys and day marks in its vicinity.

If the buoy you have sighted does not fit with the surroundings as shown on a recent chart, it is safe to conclude that you are off your course. Probably more ships have been run aground through the hasty assumption that the first buoy you sight is the one you seek than from any other single cause. At the same time, remember that buoys are apt to go adrift, especially in winter, and that those of harbors shut in by sand bars, or the buoys within jetties, are frequently moved by the local pilots as the channel changes.



FIGS. 21–24.—Starboard, port, obstruction, and channel buoys.

Red buoys with even numbers painted in black (Fig. 21) are to be left on the ship's starboard side in entering harbors. Such buoys are usually conical, and are then called " Nuns," but they may be replaced by red-colored spars, especially in harbors where ice forms during the winter. The outermost starboard buoy is marked 2, and the others follow in succession 4, 6, 8, etc., as we go further into the harbor. In long straits along our Atlantic coast, such as Long Island Sound, or the Hawk Channel, Florida, we find red buoys on the ship's starboard side as we go westward.

Black buoys, with odd numbers painted in white (Fig. 22), are to be left on the ship's port side as we enter harbor. These black buoys are usually flat topped and cylindrical; and are then called " cans," but in many places the port buoys are made of spars painted black.

Red buoys with horizontal black bands (Fig. 23) mark obstructions or shoals in the channel, and should be passed by, giving them a considerable berth on either side. These buoys are generally truncated cones, and are not usually numbered.

Buoys with black and white vertical stripes (Fig. 24 mark the deepest part of the channel and are to be passed close to. They are not usually numbered but may have distinctive marks.

Yellow buoys mark anchorages for quarantine. Mooring buoys are often white, and buoys with perches or cages on them mark turning points in channels. Bell buoys or whistling buoys may be red or black, or indicate channels; but they usually mark the seaward entrance to jetties or harbors or some important turning point in the channel, or are placed to warn vessels from rocks or sunken wrecks.

As with buoys, so with day marks, stakes, beacons and cages, red colored ones are to be left on the ship's starboard side in entering harbors, black ones mark the port side, and black and white the mid-channel.

Learn to read the chart objectively so that you form

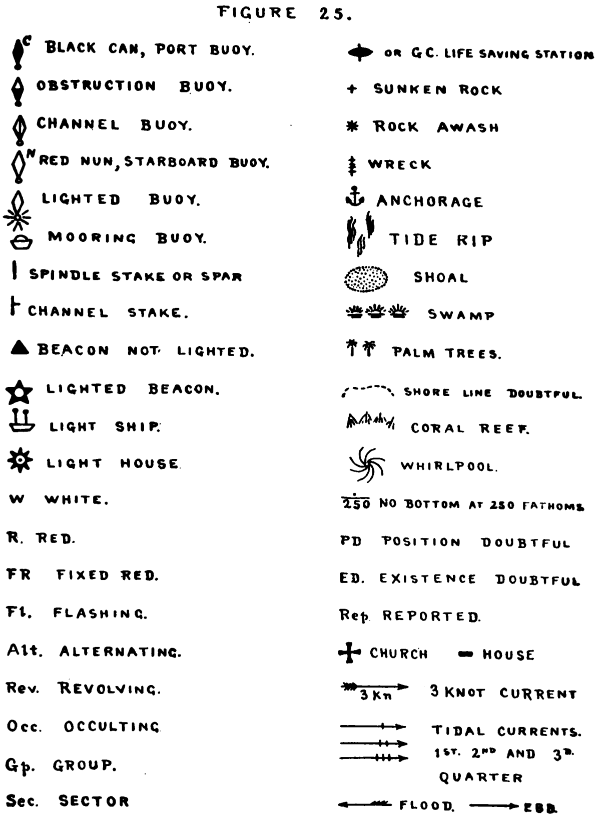


Fig. 25.—Symbols used on United States charts.

a conception of the appearance of the harbor before you enter it. Note the date of the chart, for great changes often occur after storms. Observe whether the soundings are in feet or in fathoms. Often, indeed, they are in feet over shaded areas and in fathoms over places not shaded.

The tidal and oceanic currents are often indicated by symbols on charts, as are many other important matters, such as the position of sunken rocks, wrecks, buoys, etc., as shown in Fig. 25.

In selecting an anchorage, avoid fairways, or regions where the currents are strong, and if possible choose a place in which the chart shows there is a soft muddy bottom, and let out at least three times as long a cable as there is depth. Anchor in water deep enough to avoid having a hole thrust through the bottom of your vessel by the fluke of the anchor, should you drift over it in time of low tide.

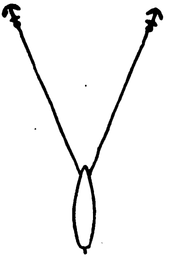


FIGURE 26.

FIG. 26.—A vessel riding to anchors close together.

If you expect a gale, it is well to use two anchors close together as is shown in Fig. 26; and in this case you will find it advantageous to have one of the anchors attached to a chain and the other to a Manila hawser, for a hawser gives gradually to a sudden strain, while a chain comes up with a sharp jerk.

In a severe gale, you may save your ship from dragging ashore by tying loops of marline or rope to heavy weights such as pigs of ballast and letting them slide down the hawser. This gives a straight pull on the anchor as is shown in Fig. 27.

If you use very heavy moorings and intend to remain long in harbor, you may use a span of chain, as shown in

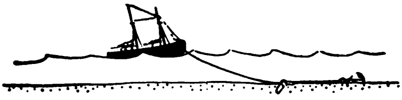


FIGURE 27.

FIG. 27.—Riding out a gale with ballast run down on the anchor cable.

Fig. 28. In this case, the ship will usually ride to one or the other of the anchors, but in cases where she rides to both, as in Fig. 28, a very heavy strain is brought upon the cables.

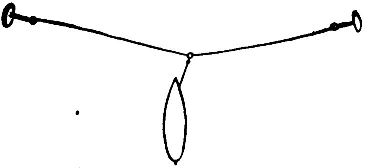


FIGURE 28.

FIG. 28.—A mooring of a span of chain.

The cables being widely separated there is no danger of fouling, and this is the chief advantage in this method of anchoring.

The navy now uses stockless patent anchors which are let out from the horse pipe. These are said not to foul, but nevertheless, they *do* foul if on a hard, smooth, rocky bottom in a tide way in which currents become reversed at the change of tides. They have the advantage that one may let go the anchor while the ship still has headway.

Remember that if we double the diameter of a rope hawser, its strength is only increased about three times, whereas with wire cable, the strength is increased at least four times. Thus the safe working strength of a manila hawser one inch in diameter is about 180 pounds while one two inches in diameter will stand 650 pounds. A flexible wire cable one inch in diameter has a working strength of 730 pounds while one two inches in diameter can be trusted to stand 3000 pounds. The chief disadvantage in wire cable is its liability to kink, especially if it becomes slack at the turn of tide in a calm. On the other hand, a chain is never stronger than its weakest link.

In riding out a storm on the open sea, a "sea anchor" or drag is often the means of saving the ship, especially if it is fitted with a bag filled with crude petroleum to flatten the crests of the waves. These drags may be made of canvas and spars weighted below to make them expose a wide vertical surface. For steamers, less than 400 tons, the area of such a drag should be at least 25 square feet, and for vessels of greater tonnage, we can estimate the proper area of the drag by the simple formula:

$$\text{Area of drag in square feet} = 25 + \frac{\text{tonnage of vessel} - 400}{25}$$

Thus the area of the drag for a steamer of 2000 tons should be 89 square feet.

In a steamer, the propeller, being a right-handed screw, usually tends to turn the bow over to starboard if the vessel is going full speed ahead, and to hold a straight course, this effect must be counteracted by the rudder. Thus steamers can generally turn to starboard in a somewhat shorter radius than they can to port. Often a steamer is able to make a sharp bend in a river turning to the right, when she would be unable to make a similar turn to the left without backing. Moreover, in making a turn, you will find that the vessel tends to pivot about a point forward of amidship, and this has a curious influence upon the vessel when turning in a current, as is shown in Fig. 29. Thus in the beginning, as shown in A, the starboard turn is made very easily for the current impigning along the starboard quarter assists the manœuvre. When the vessel has come around, however, so as to get the current on her port quarter, as at B, the turning is retarded and proceeds more slowly.

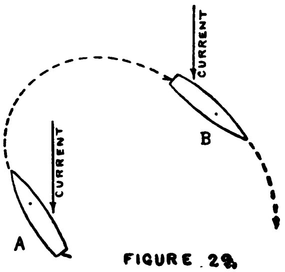


FIG. 29.—Showing the effect of a current upon the turning ability of a vessel.

A realization of this tendency to pivot about a center is of great importance in approaching a dock. You can easily haul your ship in toward a dock if you have only one line out, but if you have *two* lines attached to the wharf, one at the bow and the other at the stern, you must slack off on one while you haul in on the other, or you will never get your vessel alongside the dock.

Remember that when you turn, the stern will swing outward to a surprising extent, for the vessel is certain to pivot around a point forward of amidships, and in some vessels even forward of the bow itself.

TROPICAL STORMS

Hurricanes are unknown in the South Atlantic, but occur annually in the West Indies north of 11° N. latitude, especially during the months of August, September, and October. These storms are of limited area, rarely more than 250 miles in diameter over the region of severe winds, and at the center of the hurricane there is an area of calm where the barometer is of the lowest. As the storm moves into higher latitudes, it widens in area and decreases in intensity. At first in the West Indian, or Caribbean region, the storm center moves westerly, but between north latitude 20° to 30°, it usually curves around to the right and then goes toward the northeast over the North Atlantic, as is shown in Fig. 30. Every individual storm-path has, however, its own peculiarities and may even turn westward again after recurving, as was the case with the great Galveston hurricane of 1900.

The storm as a whole appears to be carried along by the upper air currents, and in the West Indies, when moving westerly, the center usually travels at the rate of 11 to 17 miles per hour, but when recurring between 20° to 30° north latitude, it moves more slowly and may even remain stationary for a time. Finally, however, when it reaches 40° north latitude, it travels at the rate of about 25 miles per hour. The full nature of the causes of these storms still remain unknown, but they commonly occur at the end of the hot season when the calms of summer are about to break into the steady trade winds of late autumn, and are doubtless due to the unequal heating of wide areas of ocean. The inrushing winds form an anti-clockwise swirl around the center, and may attain a velocity of from 80 to about 120 miles per hour, but these intense periods always come in sudden gusts alternating with a relatively steady gale. The shifts in direction of the wind are very apt to come suddenly with gusts, and one should observe these carefully and note their direction by the compass in order to determine the bearing of the center of the storm and the direction in which it is traveling.

Turn your face toward the wind and then the storm center will be about 10 points to your right, as will appear upon inspection of Fig. 30.

In Fig. 30, the winds as they *were* when first observed as gales are shown in dotted lines, whereas the storm as it is now is shown in full lines.

If you face the gusts and find the wind has shifted to your right, you are to the right of the path of the storm center as at B. This is a most dangerous situation, for all the winds ahead of the storm tend to blow you in toward the center of the aerial whirlpool. Above all, then, do not scud with the wind, but if you have sea room, sail on the starboard tack, as at R_1. Then, when the wind shifts, it will go more and more aft and you will not be taken aback but will gradually head around to starboard of your original course, as at R_2, and be sailing directly away from the center.

If, however, on facing the gusts you find the wind shifting more and more to the left, you are on the left

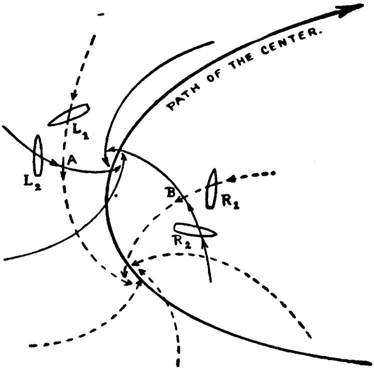


FIG. 30.—Diagram of a West Indian hurricane. The dotted lines show the directions of the wind as it *was*, and the full lines as it *is* at present.

side of the storm track, as at A. This is the navigable side of the storm; for if you bring the wind on the starboard quarter, as at L_1 and hold your compass course, you may be able to sail away from the center. The disadvantage of this procedure is, however, that the shifting wind tends to take you aback and you may be obliged to heave to, in which case, if in a sailing vessel, you should come about and lay to on the port tack, as at L_2, so that the wind will tend to drift you away from the center and the shifts of wind will draw aft; but coming about in a stormy sea is a dangerous proceeding so be guided accordingly. In a steamer, this quandary will not occur, for steamers behave best when hove to stern to the sea.

If you observe a constant falling of the barometer and an increase in the intensity of the wind with little or no change in its direction, you are in front of the center, and it is approaching; so bring the wind two points on the starboard quarter and make all the speed you can on this course until you have passed the storm track, or if in a sailing vessel and obliged to heave to, do so on the port tack. This is, of course, a hazardous proceeding, for if you are not fast enough, the center will overtake you and you will be tossed about unmercifully in a tumultuous sea in which waves come in from all directions breaking as they strike one another. Above all, never be deceived by a sudden falling off of the wind into concluding that the storm is over, but prepare for an onrush from the *opposite* direction, for in all probability you are merely passing through or near the center.

Fortunately, these storms give many warnings for about 24 hours before they develop. Often at first the atmosphere is of crystaline clarity, the barometer high, and the weather calm, but high above you will see long lines of wispy, cirrus clouds streaming in toward the distant center from the region of which a heavy roll comes over the sea. Then the air becomes hot and sullen, and the barometer falls slowly at first and then more rapidly, dark clouds appear on the horizon in the region of the storm, sunrise and sunset glare in unnatural colors; there are rings around the sun and moon, and rain and gusts of sudden wind increasing in intensity and frequency herald the coming of the storm.

We have spoken only of hurricanes in the northern hemisphere, but for those of the South Pacific and Indian Oceans, you may apply the same rules, but you must substitute port for starboard, and left for right; for in the southern hemisphere, the path of the storm is anti-clockwise and the swirl around the center clockwise, whereas in the West Indies, and Philippine Islands, the path of the storm is clockwise and the swirl around the central calm is anti-clockwise.

CHAPTER IV

TIME

We all prefer to have the day change while we are asleep, so civil time begins at midnight, but astronomers, who work at night, begin their time at noon of the previous civil day. Thus 4 P.M., civil time, October 1, is also 4 hours October 1, astronomical time; but 1 A.M., civil time, October 2, is 13 hours astronomical time October 1; for the astronomers give each hour its number and have no A.M. or P.M. We must remember that for P.M. hours civil and astronomical time are the same, but for A.M. add 12 hours to the civil time and subtract one day from the date. In working problems in navigation, you must record the astronomical time, so learn to think of 10 A.M. as 22 hours of the *previous* day.

As everyone knows, the earth revolves from west to east, making a complete rotation in 24 hours, and this causes the sun to appear to go from east to west; and, indeed, we will often speak of the sun as "going westward," for we measure time in terms of this imaginary westerly movement of the sun which is, of course, due to the easterly rotation of the earth.

In Fig. 31 let N be the north pole of the earth, and P the place upon which we are standing. Then, when the sun comes to the meridian as at M, it is noon; for the sun, the observer, and both poles of the earth are all in one and the same plane. The astronomer then says it is o h. o m. o s., while in civil time it is 12 o'clock. But the sun moves steadily westward and two hours later we find it has gone 30° away from the meridian, as at S; just as in 24 hours it will have gone 360° and have come again to the meridian. It is therefore evident that as the sun goes through 360° in 24 hours, it moves through 15° in one hour, or 1° in four minutes, 15′ in one minute, or 1′ in four seconds, 15″ in one second, and 1″ in four-sixtieths second. Evidently, then, we could measure time in terms of degrees, minutes and seconds of arc quite as readily as in the hours, minutes and seconds of time we commonly employ. Indeed, navigators and astronomers often speak of an *hour angle,* meaning simply the angle the sun makes with the meridian expressed in terms of hours, minutes and seconds, there being 15° to an hour; and thus an hour angle of 30 minutes would be equivalent to 7°30′; and the sun would make this hour angle with the meridian at 12.30 P.M. civil time, or 30 m. astronomical time; or at 11.30 A.M. civil time or 23 h. 30 m. of the previous day in astronomical measure.

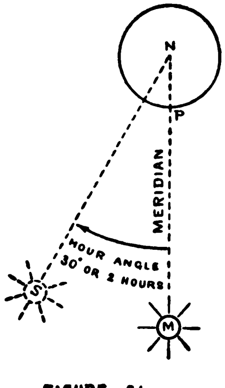


FIG. 31.—Diagram showing an hour-angle of 30° or two hours.

Example: Convert 74°40′15″ into hours, minutes and seconds.

74°	40′	15″
4	4	4
60)296 m.(4 h.	60)160 s.(2 m.	60)60(1 s.
240	120	
56 m.	40 s.	
+2 m.	+1 s.	
58 m.	41 s.	

Answer: 4 h. 58 m. 41 s.

In this example, instead of multiplying by 4 and dividing by 60, we could have divided by 15 and multiplied the remainder by 4, as follows:

15)74°(4 h.	15)40′(2 m.	15)15″(1 s.
60	30	
14 × 4 = 56 m.	10 × 4 = 40 s.	
+2 m.	+1 s.	
58 m.	41 s.	

Example: When it is noon at Princeton, New Jersey, it is 4 h. 58 m. 41 s. P.M. at Greenwich, England. What is the longitude of Princeton?

4 h.	58 m.	41 s.
15°	15′	15″
60°	60)870′(14°	60)615″(10′
14°	60	60
74°	270	15″
	240	
	30′	
	10	
	40′	

—*Answer:* 74° 40′ 15″ West.

Much tedious calculation can, however, be avoided by using Table 45, Bowditch. Thus, on page 870, Bowditch, we find 4 h. 58 m. is equivalent to 74°30′, and looking down the left hand seconds column, we see that 41 s. is equivalent to 10′15″, which being added to 74°30′, gives 74°40′15″. Table 7, Bowditch, also serves the same purpose, but is not so convenient as Table 45.

Difference of longitude is only a matter of difference of time between two places. We could begin to count longitude at any place, but as the first nautical almanac was published from Greenwich, England, this place is by convention said to be 0° in longitude. Now suppose a place were 15° west of Greenwich, then when noon came at Greenwich, the clock at the place 15° west of Greenwich would indicate 11 A.M., civil time, or 23 hours of the previous day as the astronomers would call it. When, however, it came to be noon at the place 15° west of Greenwich, it would be 1 P.M., or 1 hour astronomical time at Greenwich. We see, then, that if we are in west longitude, the time at Greenwich is always *later* than our local time, but if we are in east longitude, our local time is later than that of Greenwich.

You may find it of service to memorize the doggerel rhyme:

> "Greenwich time best longitude west,
> Greenwich time least longitude east."

We have been speaking as if we measured time by the sun, but this is not actually the case, for at times the sun is fast and at others slow. Thus on or about April 15, June 14, September 1, and December 24 the sun-dial and our clocks agree, but on February 14 the sun is 14 m. 17.4 s. slow, while on November 3, it is 16 m. 31 s. fast. It is also 3 m. 49 s. fast on May 14, and 6 m. 20 s. slow on July 26. This unequal motion of the sun is due to two causes. In the first place the polar axis of the earth is not straight up and down but inclines at 23°27′ to the ecliptic, and from this cause alone the actual solar day is shorter by 20 seconds each day at the equinoxes on March 21, or September 22, and the sun is therefore fast; conversely, it is slow at the solstices on June 21 or December 22, at which time the actual solar day is 19 seconds longer than the mean solar day. The second cause of irregularity in the length of the apparent solar day is due to the fact that the earth does not travel around the sun in a circle but in an elliptical path, and when the earth is nearest to the sun on January 1, the solar day tends to be longer than the average and the sun slow, whereas on July 1, when the earth is farthest away from the sun, the sun would be fast. It is the interaction of these two causes of irregularity and their accumulated effects, day after day, that causes the sun to be so inconvenient as a timekeeper.

Of course a clock must run at a regular rate, and cannot be made to follow these irregularities of the sun, so we imagine a *mean sun* which goes at a uniform or average rate, and our clocks keep this *mean time,* as it is called, while the actual sun keeps what we call *apparent time.* The sun-dial, of course, keeps apparent time while our watches keep mean time; and the difference between the two is called the *equation of time*. Thus on April 15, the equation of time is 0, for our clock and the sun-dial agree; but on February 14 the sun is 14 m. 17 s. slow; so when our clock showed it to be noon the sun-dial would show 11 h. 45 m. 43 s. A.M., and we would say the equation of time was –14 m. 17 s., for we would have to *subtract* this from mean, or clock time, to find sun-dial, or apparent, time.

The equation of time for every even hour throughout the year is stated on pages 6–29 of the American Nautical Almanac.

The ship's chronometer is set to keep the local mean time of Greenwich, England, or, as we call it, Greenwich mean time (G.M.T.), and in order to find our longitude we have only to determine the difference between the Greenwich mean time (G.M.T.) and our local mean time (L.M.T.). For example, suppose our chronometer showed it was G.M.T. 4 h., and by observing the sun we found our local mean time to be 2 h. Evidently we would be in 30° west longitude, for there is a difference of two hours between our time and that of Greenwich and Greenwich time is later than ours.

Of course if we were in east longitude, G.M.T. would be less than our local time. In a subsequent chapter, we will describe in detail the method of finding our local time, and hence the longitude, from an observation of the sun, but at present we may content ourselves if we understand the fundamental principle that longitude is merely the difference between the local times of Greenwich and the place we are in, the difference in longitude being simply a matter of difference of time. Of course if we use Greenwich mean time we must compare it with local mean time, but if we use Greenwich apparent time, we must compare it with local apparent time.

SIDEREAL TIME AND SOLAR TIME

Our chronometers and clocks keep mean solar time, but if we were nocturnal animals, we would probably prefer

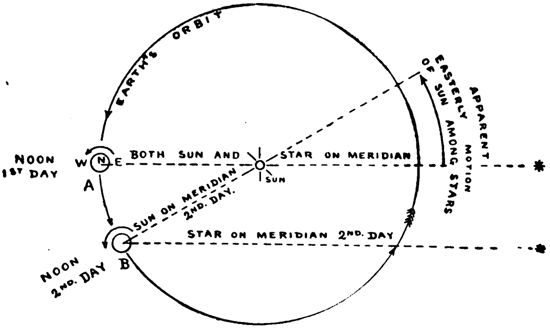


FIG. 32.—Diagram showing the relation between solar and sidereal time.

to keep time by the stars instead of by the sun; for we could use the stars quite as well as the sun to keep time for us. To illustrate this we have made a diagram (Fig. 32), showing the sun as if it were a small transparent body at the center of a circle representing the earth's orbit. The earth we have shown as of large size, and we assume it to be upright instead of its poles being inclined 23°27′

to the ecliptic, as they actually are; and we are looking down upon the north pole. We also imagine that the earth goes around the sun in 16 days instead of 365¼, so that it would move through 22.5° of its orbit in a day. All these assumptions are made for the purpose of more clearly illustrating the principles underlying the relationship between solar and sidereal time.

Suppose, then, the sun were not only transparent, but that it gave so little light that at noon when the earth was at *A* we could look right through the sun and see that we ourselves, the sun, and a bright star were all three in one line. Now let the earth move onward on its orbit, and at the same time rotate on its axis so the sun comes again to our meridian on the following day, as at *B*. Judging from the sun, we would then call it noon of the following day, but we see that owing to the fact that the stars are vastly far away from us, all lines extending from the earth to the star are parallel no matter where the earth is in its orbit, and thus the star has not changed its direction as seen from the earth, so star-noon, as we see in Fig. 32, comes before sun-noon. In other words, the sidereal day is shorter than the *solar* day, and owing to the fact that the earth moves around the sun, it loses a day in so doing, but there is no such loss in respect to the stars, for the earth does not move around them; so there are 365¼ solar days and 366¼ sidereal days in the year. Thus according to the stars there are 23 h. 56 m. 4.09 s. in a day, while the mean solar day is 24 hours.

Astronomers, however, have sidereal clocks which keep star time with 24 hours in the sidereal day, each sidereal day being 3 m. 55.9 s. shorter than the mean solar day, and thus the sidereal clock gains a whole day in a year on the ordinary clock. These sidereal clocks keep the local sidereal time of the observatory, and the sidereal day begins when an arbitrarily selected position in the heavens, called the *first point in Aries* comes to the meridian, just as the solar day begins when the sun comes to the meridian. Unfortunately, there is no bright star to mark the first point in Aries, but it is close to the place wherein the plane of the ecliptic crosses the plane of the earth's Equator; and we will have more to say concerning it when we come to describe the methods of getting latitude and longitude from the stars.

Now, to refer again to Fig. 32, we see that the effect of the earth's movement around the sun is to cause the sun to appear to move *eastward* among the stars, consequently the stars must move *westward* with respect to the sun, and in fact the stars rise earlier and set earlier by 3 m. 55.9 s. each day; due to the fact that the sun appears to move eastward among the stars at an average rate of 59′ 8.33″ per day, thus making the circuit of 360° in the year, so that the sidereal clock agrees with the solar clock only at the vernal equinox on March 21–22 of each year, and at all other times the sidereal clock is more and more fast in comparison with the solar clock, gaining a whole day in the year. Astronomers use the first point in Aries as the position from which to measure celestial longitude, very much as navigators use Greenwich as the position from which to measure longitude on the earth. There are some differences, however, for we call celestial longitude *right ascension* and measure it all the way around *toward the east,* whereas in the case of the earth, we speak of east or west longitude, measured eastward or westward from Greenwich to the 180° meridian which cuts through the Fiji Islands near the middle of the Pacific.

Moreover, we usually measure terrestrial longitude in terms of arc, whereas we designate right ascension in terms of hours, minutes and seconds.

As the sun appears to pass eastward all around the heavens in the course of the year, its right ascension continually increases by about 3 m. 55.9 s. each day, and is given for Greenwich mean noon of every day on pages 2–3 of the American Nautical Almanac.

Of course the right ascension of the mean sun (R.A.M.S.) at noon at Greenwich is the same as the Greenwich sidereal time (G.S.T.).

Suppose, however, we wished to find the Greenwich sidereal time at some time other than noon at Greenwich. For example: On June 21, 1918, the Greenwich mean time is 4 h. 8 m. What is the Greenwich sidereal time?

G.M.T.	4 h. 8 m. June 21
R.A.M.S. at Greenwich mean moon, June 21, 1918, page 2, American Nautical Almanac	5 h. 55 m. 29.4 s.
Correction for 4 h. 8 m. past noon, from the botttom of page 2, American Nautical Almanac	+ 40.4 s.
Answer ........................G.S.T.	10 h. 04 m. 09.8 s.

Example: What is the local sidereal time in east longitude 60°, the Greenwich mean time being 8 h. 12 m., January 11, 1918?

G.M.T.	8 h. 12 m.	January 11
R.A.M.S., January 11, at noon....	19 h. 20 m. 44 s.	
Correction for 8 h. 12 m.	20 m. 20.8 s.	
G.S.T.	27 h. 34 m. 04.8 s.	January 11
G.S.T.	3 h. 34 m. 04.8 s.	January 12
Time interval for 60° E. Long...	+4 h.	
Answer: Local sidereal time....	7 h. 34 m. 04.8 s.	January 12

Example: In west longitude 75° the Greenwich mean time is 12 h. 42 m., June 1, 1918. What is the local sidereal time?

G.M.T.	12 h. 42 m.	June 1
R.A.M.S. at mean noon at Greenwich, June 1, 1918	4 h. 36 m. 38.2 s.	
Correction for 12 h. 42 m. past noon..	+2 m. 5.2 s.	
G.S.T.	17 h. 20 m. 43.4 s.	
W. Long. 75° in time	−5 h.	
Answer ...................L.S.T.	12 h. 20 m. 43.4 s.	

Example: In longitude 90°40′ west, the local mean civil time is 2 h. 43 m. P.M., July 6, 1918. What is the astronomical Greenwich mean time?

Astronomical local mean time	2 h. 43 m.	July 6
W. Long. 90°40′ in time.............	+6 h. 02 m. 40 s.	
Answer ...................G.M.T.	8 h. 45 m. 40 s.	July 6

Example: In longitude 90°40′ west, the local mean civil time is 10 h. 15 m. A.M., July 6. What is the astronomical Greenwich mean time?

10 h. 15 m. A.M. civil time, July 6 = 22 h. 15 m., July 5, astronomical time.

W. Long. 90°40′ in time........	+6 h. 02 m. 40 s.	
Answer .............G.M.T.	28 h. 17 m. 40 s.	July 5
	or 4 h. 17 m. 40 s.	July 6

Example On July 10, 1918, in west longitude 90°, the Greenwich mean time is 7 h. 40 m. What is the local mean time–

G.M.T.	7 h. 40 m.
90° W. Long. in time	–6 h.
Answer ...............................L.M.T.	1 h. 40 m.

Example: On February 18, 1918, it is noon at Greenwich by Greenwich mean time. What is the astronomical Greenwich apparent time?

Astronomical G.M.T.	0 h. 00 m. 00 s.	February 18
Equation of time February 18 from American Nautical Almanac	— 14 m. 8.2 s.	
Answer .............G.A.T.	23 h. 45 m. 51.8 s.	February 17

Example: On May 8, 1918, in W. long. 45°, the astronomical Greenwich mean time is 2 h. .05 m. What is the local astronomical apparent time?

G.M.T.		2 h. 05 m.	May 8
Equation of time, May 8...............		+3 m. 36.3 s.	
	G.A.T.	2 h. 8 m. 36.3 s.	May 8
	G.A.T.	26 h. 8 m. 36.3 s.	May 7
W. Long. 45° in time................		−3 h.	
Answer	L.A.T.	23 h. 8 m. 36.3 s.	May 7

Example: On March 15, .918, what is the Greenwich mean time of apparent noon in west longitude 74°?

G.M.T. of mean noon = 74° W. Long. in time =	4 h. 56 m.
Equation of time for Nov. 15 with sign *reversed,* the apparent sun being *fast*........	−15 m. 22.6 s
Answer ...........GM.T. of apparent noon	4 h. 40 m. 37.4 s.

CHAPTER V

THE SEXTANT

THE great Portuguese explorers under Prince Henry, the Navigator, seem to have been the first to realize the necessity for improving the means of observing the angular height of the sun above the horizon at noon in order to determine latitude.

The earliest instrument for this purpose seems to have been the cross staff (Fig. 33), which was simply a wooden bar with a sliding cross-piece. One end of the bar being held near the eye, the cross-piece was caused to glide along the bar until its upper end appeared to touch the sun, and the lower end the horizon. Then the scale on the bar was graduated to indicate the angle, and from this the latitude could be determined within about 100 miles. Columbus appears to have used such an instrument upon his famous voyage in 1492.

The astrolabe used by Vasco da Gama in 1497 was an attempt to improve upon the cross staff. It was a heavy metal disk (Fig. 34), which was suspended by a string. The disk was then turned into the plane of the meridian and the sight-vane was pointed toward the sun, thus enabling one to read off the angle on the graduated edge of the disk. Taking an observation with this affair was an elaborate process and three men were usually concerned in it; one to hold the rope which suspended the

FIGURE 33

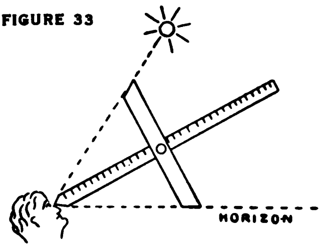


FIGURE 34

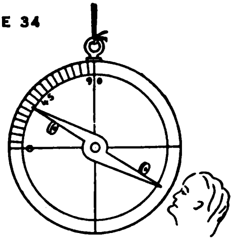


FIGURE 35

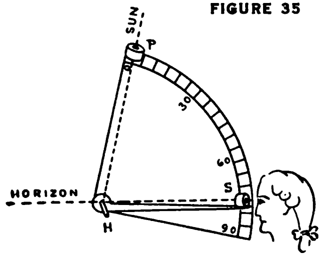


FIG. 33.—Cross staff for obtaining the altitude of the sun. Used by Columbus in 1492.

FIG. 34.—The astrolabe, an instrument used by Vasco da Gama in 1497.

FIG. 35.—Lighted pin quadrant invented by Wright and Davis in 1729.

disk, one to turn it into the plane of the meridian, and the third to sight upon the sun.

A decided improvement was effected by Wright and Davis in 1729, who devised the instrument shown in Fig. 35. You stood with your back to the sun, and the light passing through the peephole (P), illuminated the pin (H). You then moved the sight disk (S) until the illuminated pin appeared in line with the horizon, and read off the angle on the scale.

The first reflecting sextant was devised by Sir Isaac Newton in 1699, who showed it to the members of the Royal Society, but no one seemed to appreciate the importance of the invention, and the description of the instrument in Newton's handwriting was found more than forty years afterwards among Halley's papers and published in the Philosophical Transactions of the Royal Society of London. Newton's instrument is illustrated in Fig. 36. The telescope (T) was about 4 feet long and was rigidly attached to the scale-plate. Immediately in front of the telescope, there was a half-silvered mirror (H) arranged so that one could see the horizon through the unsilvered part, while the silvered portion reflected an

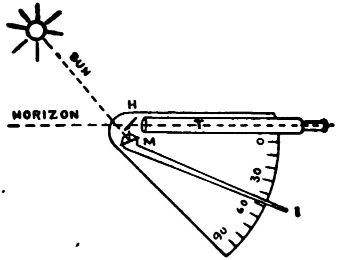


FIGURE 36

FIG. 36.—Newton's reflecting quadrant, invented in 1699.

image received from another completely silvered mirror (M) attached to the pivoted index (I). One read off the angle on the scale which was graduated in half arc, as in the modern sextant, to compensate for the double reflection by the mirrors.

Newton's instrument was re-invented independently by Thomas Godfrey, a glazier of Philadelphia, in 1730, and also by John Hadley of London in 1731; but within a year Hadley devised the form of the sextant which is the type we now use, and which is shown diagrammatically in Fig. 37. The telescope (T) and the horizon-mirror (H) are rigidly attached to the frame of the instrument. The horizon-mirror is half silvered and half plain glass, so that we may look through the unsilvered part and see the horizon, while the silvered part serves to reflect the image of the sun received from the mirror (M). This mirror (M) is large and completely silvered, and is attached to the index (I) so that it may be turned at various angles. If the mirrors (M)

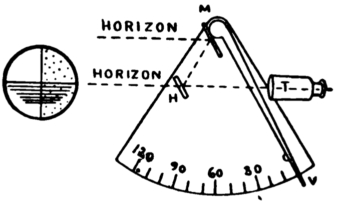


FIGURE 37.

Fig. 37.—Hadley's sextant set to read 0°, so that the reflection of the horizon coincides with the direct view of the horizon seen through the telescope. The dotted area is the reflecting surface of the horizon mirror H.

and (H) are parallel, as shown in Fig. 37, the reflected image of the horizon will be continuous with the horizon as seen directly through the telescope, and the index should then read 0°. If if reads below 0°, we must add this index correction, as it is called, to every reading of the instrument, for every angle will appear too low. If, on the other hand, it reads above 0°, it is evident that every angle we read off on the scale will be too high, so we must subtract the index correction. This index correction is apt to change, and we should therefore determine it frequently, either by bringing the reflected image of the horizon into coincidence with the direct view of the horizon as seen in the telescope, or by making the direct image of a bright star coincide with its reflected image.

If the index error is less than 2′ and does not change to any large extent as the sextant is heated, cooled, or jarred by use, you had better not attempt to get rid of it; but simply allow for it at each observation. This error is chiefly due to two causes: In the first place the index mirror must be perpendicular to the plane of the sextant, and to test this set the index to about 60° near the middle of the scale and hold the sextant in a horizontal position. Then place your eye close to the index mirror and see if the reflected image of the arc of the scale is in a continuous curve with the scale itself. If the reflected image appears to rise, the index mirror leans forward and if it droops it leans backward, and it may be adjusted by set screws at the back of the mirror.

Now hold the sextant in a vertical position and set the index accurately to 0° on the scale. Sight on the horizon, and if you have no index error the reflected image of the horizon seen in the silvered part of the horizon glass will be continuous with the direct image seen through the unsilvered part. If they do not coincide, move the horizon mirror in azimuth by means of the set screws at its back until the coincidence is perfect.

The reflected and the direct images of the horizon may coincide when the index is at 0° if the sextant is vertical, but not if it is inclined, and this shows that the plane of the horizon mirror is not perpendicular to the plane of the sextant, so make this adjustment by means of a set screw placed for this purpose at the back of this mirror.

In using the sextant avoid heating it in the sun, touching the mirror, or jarring the instrument, for this will change the index error.

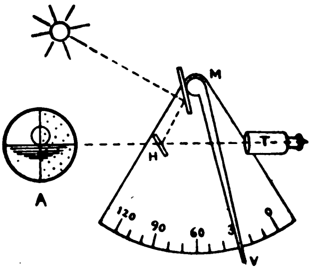


FIGURE 38.

FIG. 38.—Hadley's sextant set to read the altitude of the sun at 30°. The lower limb of the sun is "kissing" the horizon as is shown in A, which represents the view seen in the telescope.

One can easily see that if we move the index forward, as in Fig. 38, we will come to an angle at which the sun is reflected from the two mirrors so that both it and the horizon are seen in the telescope. We may then bring the sun into such a position that its lower limb "kisses" the horizon, as in Fig. 38A, and read off the altitude on the scale.

When you get the sun's image in the telescopic field, rock your sextant from one side to the other so as to cause the sun to describe the arc of a circle, as shown in Fig. 39. Then make its lower limb touch the horizon at the lowest part of this arc, vertically under the sun, and this will give you a good observation of the altitude. The beginner is apt to read off too high an altitude, for if he fails to rock his sextant he will probably not get the vertical distance, but one which makes a more or less slanting angle with the horizon.

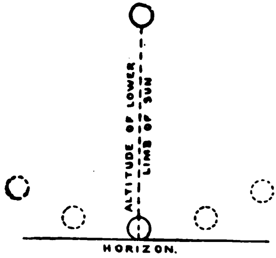


Fig. 39.—Showing that by rocking the sextant, we cause the reflected image of the sun to describe an arc, and can thus determine the point of tangency of the sun's image with the horizon, and obtain the altitude.

However, one cannot learn to use a sextant by reading about it, but a few hours' practice under the direction of a master mariner will give you such a start that you can soon make yourself expert in its use.

Always take the altitude of the lower limb of the sun unless you are forced by circumstances, such as clouds, to do otherwise; for you will find it easier to get a good tangency between the sea-horizon and the lower edge of the sun than between the upper limb of the sun and the air above the sea.

Use the shade-glasses so as to deaden the brightness of the sun, and in the afternoon when the horizon is glaringly illuminated, you will find the use of the green horizon-glass convenient. Take short glances through the telescope at frequent intervals, and do not strain your eye, for this will prevent your getting an accurate observation. Use both hands in holding the sextant, taking most of the weight off with your left hand, as if holding a rifle, thus enabling your right to rock the sextant without becoming

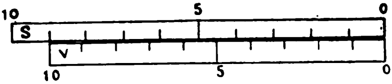


FIGURE 40.

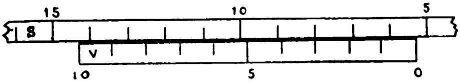


FIGURE 41.

FIG. 40.—A scale (S) and vernier (V) in which each division on the vernier is 1/10 less than a division on the scale. Thus the vernier reads to 1/10 of a scale division.

FIG. 41.—Three on the vernier coincides with a division of the scale, and the reading is therefore 5.3.

tired, while you manipulate the tangent screw with the thumb and middle finger of your left hand.

Above all, you must learn to read the vernier. This arrangement was invented by Pierre Vernier in 1631, and consists of a sliding scale which is divided in equal spaces into one more or one less division in a given length than the divisions of the scale you desire to read.

For example, in Fig. 40, 9 divisions on the scale correspond with 10 divisions on the vernier, and thus the vernier reads to $^1/_{10}$ of a division of the scale. Or, in general, if V divisions of the vernier correspond with S divisions on the scale, the vernier reads down to $\frac{V-S}{V}$, which in this case is $\frac{6-01}{10} = \frac{1}{10}$.

Now suppose we slide the vernier along the scale: If the number 1 on the vernier is pushed forward by $^1/_{10}$ of a division, it will coincide with 1 on the scale. The number 2 on the vernier must be pushed along $^2/_{10}$ to make it coincide with 2 on the scale, etc.; and a little study will show that if the vernier and scale were placed as shown in Fig. 41 the reading is 5.3, for the 0 of the vernier is somewhere between 5 and 6 on the scale, and 3 on the vernier coincides with a division on the scale. Thus we read the tenths off directly on the vernier, merely looking for the first coincidence with some division of the scale beyond the 0 of the vernier. Trace this vernier on a piece of paper; and slide the vernier along the scale, and after a little practice you will be able to read the vernier perfectly.

Indeed, you can always guess with a fair degree of accuracy just where a coincidence will come; for, suppose the 0 of the vernier fell about one-third way between 5 and 6 on the scale, as in Fig. 41, evidently the reading must be about 5.3 and you would at once look for a coincidence between 3 on the vernier and some division on the scale.

Common types of sextant scales and verniers are where 19 divisions on the scale correspond with 20 on the vernier, in which case the vernier reads to $^1/_{20}$ of the scale, as shown in Fig. 42.

In another form, shown in Fig. 43, 14 divisions on the scale correspond with 15 on the vernier, so the vernier reads to $^1/_{15}$ of the scale divisions, as in Fig. 43.

The scale and vernier of the standard marine sextant

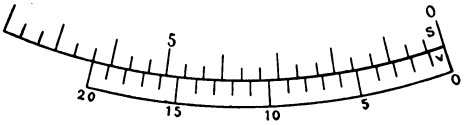


FIGURE 42.

FIG. 42.—Nineteen of the smaller divisions on the scale are equivalent to 20 on the vernier, so the vernier reads down to 1/20 of a scale division. Thus if the smaller divisions on the scale were 20′, the vernier would read down to 1′.

is shown in Fig. 44. Here the large divisions of the vernier read to 1′ and the smaller to 10″. Thus, if scale and vernier coincide as in Fig. 45, the reading would be 10°42′50″, for we see that the 0 of the vernier is beyond

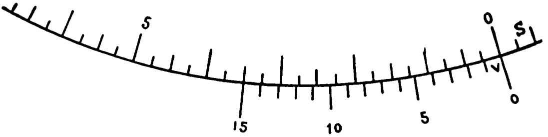


FIGURE 43.

FIG. 43.—Fourteen of the smaller divisions on the scale are equal to 15 on the vernier, so the vernier reads to 1/15 of the smallest scale divisions. Thus if the small divisions on the scale represented 15′, the vernier would read to 1′.

10°40′ on the scale, and at 2′50″ on the vernier we find a coincidence with a division of the scale. Hence the reading is 10°40′ + 2′50″ = 10°42′50″. If you will trace these verniers and slide them along their scale, you will soon become proficient in reading them.

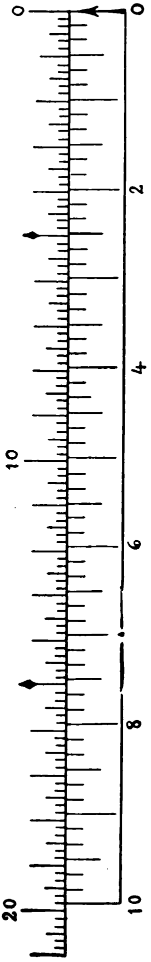


FIGURE 44.

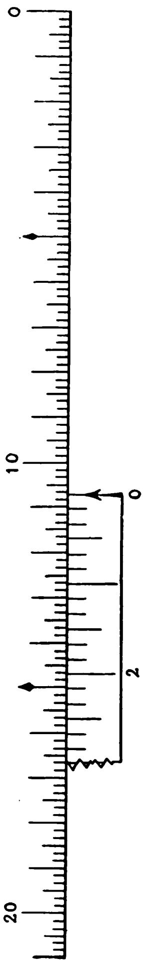


FIGURE 45.

FIG. 44.—Type of scale and vernier of the standard sextant. The vernier reads to 10″.

FIG. 45.—A vernier on the standard sextant scale reading 10°42′50″.

CHAPTER VI

CORRECTING THE ALTITUDE

THE sextant is used for measuring the altitude, or angular height of the sun, moon, stars, or planets above the horizon. In all cases, we desire to know the altitude of the center of the heavenly body, or the *true central altitude* (T.C.A.) as it is called. Of course this is easily found in the case of a star or planet, for these are practically mere points of light, their diameters being too small to be considered in navigation.

In the case of the sun and moon, however, we should observe the altitude of the lower edge, or *limb,* as it is called, and then, knowing the radius, or *semi-diameter,* we can calculate the true central altitude. The semi-diameter of the sun ranges from 16′18″ on January 1, when the earth is nearest the sun, to 15′46″ on July 1, when we are farthest away; but navigators usually take the average, or 16′, as its semi-diameter at all seasons, for we never make an error of much more than a quarter of a mile by so doing, and if we determine our position at sea within a mile we are doing well.

If we have brought the sun's *lower* limb down to the horizon, we must *add* the semi-diameter to the observed altitude to find the true central altitude, as is shown in Fig. 46, and conversely, if we observed the sun's *upper* limb, we would have to *subtract* the semi-diameter.

But there are also other corrections to be applied to the observed altitude. In the first place, the earth is

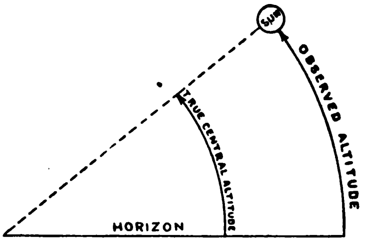


FIGURE 46.

FIG. 46.—Showing the relation between the true central altitude and the observed altitude of the sun's lower limb.

spherical and our eye is always above sea level, and this makes the observed altitude too great, as is shown in Fig. 47.

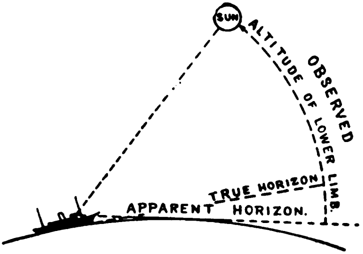


FIGURE 47.

FIG. 47.—Illustrating dip due to the eye's being above the surface of the sea.

This error is called *dip*, and is always subtractive. It is given in Table 14, page 685, Bowditch, for heights of eye ranging from 1 to 100 feet, but for purposes of navigation, we may assume the dip in minutes of arc to be equivalent to the square root of the height of the eye in feet, and the error will be practically negligible, as is shown in the following table:

Height of eye in feet above sea level	Square root of the height of the eye	True dip from Table 14, Bowditch
9	3′	2′ 56″
16	4′	3′ 55″
25	5′	4′ 54″
36	6′	5′ 53″
49	7′	6′ 56″
100	10′	9′ 48″

Another error is caused by the earth's atmosphere which refracts or bends the light, thus making altitudes appear too great, as shown in Fig. 48, where the sun

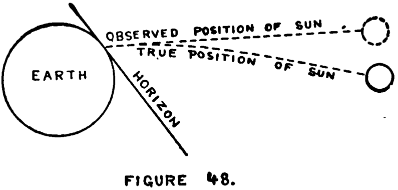


FIG. 48.—Showing the effect of atmospheric refraction in increasing the altitude of the sun.

appears to be in the dotted position while it is really in the position drawn in full lines. Of course, refraction does not occur if the heavenly body is in the zenith, but it becomes more and more important as the altitude declines, and when a star appears to be on the horizon the refraction is about 36′29″ and the star is actually more than half a degree below the horizon when it appears to be setting.

The following, taken from Table 20A, Bowditch, will show how rapidly refraction increases as the altitude declines:

Observed altitude	Average refraction
90°	0′ 0″
60°	0′ 34″
45°	0′ 58″
20°	2′ 39″
10°	5′ 19″
5°	9′ 52″
0°	36′ 29″

Table 20A, Bowditch, gives the refraction for stars; but Table 20B, which combines refraction and parallax, is for use in observing the sun. Refraction is so variable that it is a constant source of uncertainty, especially on calm, hot days when distant objects seem to "lift" above the sea. On clear, crisp, windy days, it is about as stated by Bowditch, but if great accuracy is desired, one should not take altitudes lower than 20°, for refraction is especially variable at low altitudes, and over hot waters such as the Red Sea or Persian Gulf it may give rise to errors of from 7′ to 10′.

Parallax is the difference between the position of a heavenly body as seen from the center of the earth, and from a point on the surface of the earth. It is greatest when the moon or sun are on the horizon, and vanishes when they are in the zenith, as will be seen in Fig. 49, where, if the moon is in the zenith, as at A, there is no parallax and it appears to be in line with the star A′, but if we were at B the moon would be on the horizon and would appear to be in line with the star B′.

As the moon is so near, its horizontal parallax is very large and variable, ranging from 53′ to about 60′, depend-

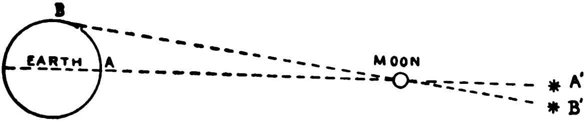


FIGURE 49.

FIG. 49.—Illustrating horizontal parallax of the moon.

ing upon the moon's distance, its altitude, and the latitude of the ship.

On the other hand, the sun being about 92,500,000 miles away, its parallax is never more than 9″, and therefore practically negligible; but it is allowed for in Table 20B, page 689, Bowditch. Being vastly distant, the stars have practically no parallax, and even the parallax of the planets may be neglected by the navigator.

Parallax tends to make observed altitudes too low, so we must *add* to correct for it.

To recapitulate: the following corrections must be made to reduce an observed altitude of the sun to the true central altitude:

Nature of the correction.	Amount of the correction.
1. Index correction of the sextant	Either + or −, dependent on the instrument.
2. Semi-diameter	See American Nautical Almanac, or add 16′ for lower, or subtract 16′ for upper limb.
3. Dip in minutes of arc......	See Table 14, Bowditch, or subtract $\sqrt{\text{Height of eye in feet}}$.
4. Refraction and parallax....	See Table 20B, Bowditch. As the parallax is small, this combined error is always subtractive in the case of the sun.

Instead of making these corrections individually, we may use Table 46, Bowditch, which at once gives the amount to be *added* to the observed altitude of the sun, or subtracted from that of a star, to obtain the true altitude.

If possible, always use a table and avoid complex calculations which may lead you into error and jeopardize the ship. At the same time, we should know the underlying principles of navigation, so the following examples are suggested for practice:

Example: An observed altitude of the lower limb of the sun gave 43° 18′30″. Index correction of sextant −1′40″. Height of eye 16 feet. What is the true central altitude?

Observed altitude...	43° 18′30″	Dip for H. of E. 16 feet, Table 14, Bowditch	−3′55″
Index correction....	−1′40″	Refraction and parallax for 43°20′, Table 20, Bowditch	−55″
Sextant altitude.....	43° 16′50″		−4′50″
Correction	+11′10″	Semi-diameter of sun's lower limb	+16′00″
True central altitude (T.C.A.)	43°28′00″		−4′50″
		Correction	+11′10″

In the case of the stars, there is no correction for semi-diameter, and no parallax.

Example: An observed altitude of Aldebaran gave 14° 10′40″. Index correction +2′30″. Height of eye 27 feet. What was the true altitude?

Observed altitude...	14°10′40″	Dip. H. of E. 27 feet, Table 14, Bowditch...	−5′06″
Index correction....	+2′30″	Refraction for 14°10′, Table 20A, Bowditch.	−3′46″
Sextant altitude.....	14°13′10″		
Correction	−8′52″		
True altitude	14°4′18″	Correction	−8′52″

In the case of the moon, the correction for parallax is so important that the corrections for semi-diameter, dip and index correction should be applied first and the approximate altitude thus found may be looked up in Table 24, Bowditch, to find the parallax and refraction.

Moreover, the semi-diameter varies with the altitude becoming greater as the altitude increases, due to the fact that the moon is nearer to the observer when in the zenith, by nearly the radius of the earth, than when on the horizon. This correction may be found in Table 18, Bowditch.

Finally, the semi-diameter and horizontal parallax change from hour to hour and must be looked up in the American Nautical Almanac for the exact time of the observation.

Example: On November 8, 1918, at G.M.T. 4 h. 30 m., the observed altitude of the moon's lower limb was 20° 15′. Height of eye 20 feet. Index correction +1′. What was the true central altitude?

Semi-diameter of moon on Nov. 8, at G.M.T. 4 h. 30 m. from American Nautical Almanac.	+15′18″
Augmentation for 20° altitude, and semi-diameter 15′, Table 18, Bowditch	+5″
	+15′23″
	−3′23″
First correction.....	+12′00″
Observed altitude....	20° 15′
Approximate altitude.	20° 27′
Parallax and refraction, Table 24, Bowditch	+49′53″
T.C.A.	21° 16′ 53″

Dip H. of E. 20 feet, Table 14, Bowditch..	−4′23″
Index correction........	+1′
	−3′23″
Horizontal parallax from American Nautical Almanac	55′55″
Parallax and refraction for 56′ horizontal parallax and 20° 30′ altitude. Table 24, Bowditch	+49′53″

The observed altitude of the moon is usually about a degree lower than the true central altitude, and the correction is so large and uncertain that the result is not very reliable. If possible, therefore, use stars to find your position, and observe the moon only when obliged to do so. Moreover, instead of making the elaborate calculation described above, use Table 49, Bowditch, which is calculated for a height of eye of 35 feet above sea level; but a supplemental table on page 947 gives the allowance for altitudes other than 35 feet. Thus in the example cited above, we find on page 946, Bowditch, for 20° observed altitude and 56′ horizontal parallax, a correction of +59′31″, and to this we must add 1′23″ for height of eye of 20 feet; and 1′ more for the index correction of our sextant, giving a total correction of 61′54″, whereas our calculation gave it 61′53″.

CHAPTER VII

LATITUDE

As every one knows, the sun rises higher and higher until noon, after which it declines until sunset. Now, if we know the date, our approximate longitude, and the altitude of the sun at noon, we can easily find the latitude of the ship.

By latitude we simply mean our angular distance north or south of the Equator. Thus the latitude of the North Pole is 90° N., of the South Pole 90° S., of the Equator 0°, of New York City N. 40°42′, etc. Moreover, if we know the latitude, we can tell how many nautical miles a place is north or south of the Equator, for each 1′ of latitude is a nautical mile, and thus the Brooklyn Navy Yard, which is in 40°42′ N. Lat. is 2442 miles north of the Equator.

Of course, the sun keeps apparent time, and as it is about 14 minutes slow in February apparent noon will come about 14 m. after mean noon; and similarly in November, when the sun is about 16 minutes fast, it reaches the meridian at about 11.44 A.M., local time.

At sea, we are usually somewhat uncertain of our position, so it is well to begin to sight the sun with the sextant about 15 minutes before apparent noon. We then bring the lower limb of the sun down until it appears to be tangent to the horizon, at the same time rocking the sextant to make sure you have the true altitude. Then set the sextant aside for a few minutes, and upon again glancing at the horizon, you will find the sun has risen above the sea; so bring it down to the horizon again by means of the tangent screw. Repeat this process at intervals and you will find that while the sun rose rapidly at first, it goes upward more and more slowly as noon approaches; and for about two minutes around noon its motion is almost wholly westward, with no appreciable change in altitude. Soon after this the lower edge of the sun begins to dip below the horizon, and you know that it is past noon, so set your cabin clock to 12, and ring 8 bells. When the sun dips, do not bring it up to the horizon again or you will spoil your observation, but take the altitude when the sun reaches its highest point.

Suppose you are in New York City in 74° west longitude, on February 16, 1918. What is the Greenwich mean time and also the local mean time of local apparent noon?

W. Long. 74° in time	4 h. 56 m.
On February 16, apparent sun is slow	14 m. 15.7 s.
G.M.T. of local apparent noon	5 h. 10 m. 15.7 s.

New York keeps the local time of the 75th meridian, and thus when the clocks show it is noon in New York, it is 5 P.M. in Greenwich; so that on February 16, 1918, local apparent noon would come at 12 h. 10 m. 15.7 s. by the New York clocks, or 0 h. 10 m. 15.7 s. local astronomical time.

Having watched the sun and determined the altitude of its lower limb at local apparent noon, let us see how we may find the latitude of the ship.

In the first place, we must know the declination of the sun, and the American Nautical Almanac gives this for every even hour throughout the year. The declination is

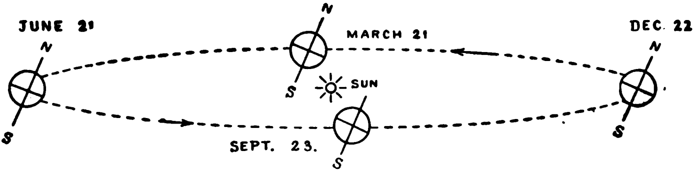


FIG. 50.—Showing the sun's declination at the solstices, and at the equinoxes.

simply the angle the sun makes with the plane of the Equator. Thus on June 21, the sun is 23°27′ north of the Equator. It then goes south, reaching the Equator on or about September 23; and 23°27′ south of the Equator on December 22; after which it again comes north, reaching the Equator on March 21, as is illustrated in Fig. 50.

But to proceed to the question of determining the latitude, suppose we were north of 23°27′ in summer. The sun would be south of us at noon because 23°27′ is as high as it ever comes; therefore the altitude will be south, or —.

Of course if we were south of south latitude 23°27′, the altitude of the sun would always be north, or +; and if we were within the tropics, the sun would be sometimes north and sometimes south of us, dependent upon its declination.

Fig. 51 represents the conditions as seen from about

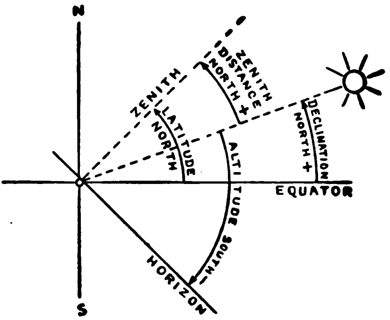


FIGURE 51 LAT. = $\overset{+}{\text{Z.D.}} + \overset{+}{\text{DEC.}}$

FIG. 51.—Illustrating the method for finding latitude from a noon altitude of the sun, the observer being north of 23°27′ N. Lat., with the sun in north declination.

N. Lat. 40° in summer. NS is the polar axis of the earth. The sun is north of the Equator and therefore its declination (Dec.) is +. The zenith, which passes through our body and the center of the earth and extends upward, is, of course, perpendicular to the horizon; while the horizon is tangent to the earth at our feet. The altitude (Alt.) of the sun is the angular height of its center above the horizon; and 90°− the altitude is called the *zenith distance* (Z.D.), which in this case is north of the sun or +, while the altitude is south of the sun or −.

Indeed, zenith distance and altitude always have opposite signs; if altitude is N., or +, zenith distance is S., or −, and *vice versa.*

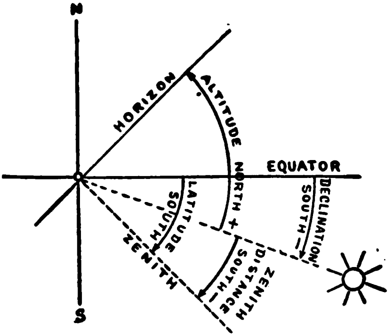


FIGURE 52. LAT.= $\overline{Z.D.}$+$\overline{DEC.}$

FIG. 52.—Illustrating the method for finding latitude from a noon altitude of the sun in the southern hemisphere south of 23°27′ S. Lat. with the sun in south declination.

Fig. 51 shows that zenith distance (Z.D.) = 90°− altitude. Also: Latitude = Declination + Zenith Distance.

In fact, the latitude is always the algebraic sum of the declination and the zenith distance; but we must be careful about the signs and call North + and South −.

For example, suppose we were in south latitude, south of the sun, in December, as shown in Fig. 52. Here the sun's declination is south or –, the altitude is north, or +, and consequently, the zenith distance is –. Now, remembering that Lat. = Z.D. + Dec., and that in this case both Z.D. and Dec. are negative, the latitude is the sum of the two negative quantities (–Z.D.–Dec.). Thus, suppose the Z.D. were –20 and the Dec. –23°, the latitude would be S. 43°.

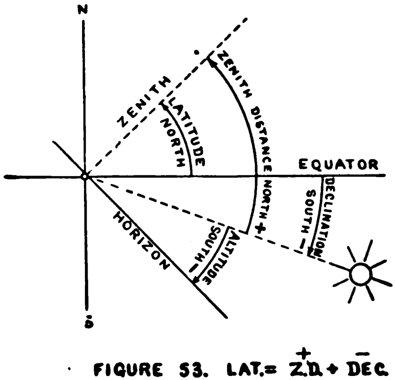


FIG. 53.—Illustrating the method for finding latitude in the northern hemisphere when the sun is in south declination.

A third case is shown in Fig. 53, wherein the observer is north of the Equator in winter. Here Z.D. is +, while Dec. is –, and the latitude is therefore (+Z.D.–Dec.); and if Z.D. were 50° N. and Dec. 20° S., the latitude would be N. 30°.

Another case, shown in Fig. 54, represents the condition in the southern West Indies in late June, where the observer is in N. Lat. and the sun north of the Equator, its declination being greater than the latitude. Here, again, Lat. = Z.D. + Dec., and as Z.D. is –, and Dec. +, we subtract the one from the other. Thus, if the declination were +23° and zenith distance –10°, the latitude would be N. 13°.

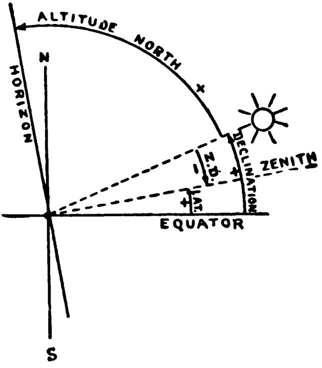


FIGURE 54. LAT.= $\overset{-}{\text{Z.D.}}$ + $\overset{+}{\text{DEC.}}$

FIG. 54.—Illustrating the method for finding latitude from a noon altitude in the northern hemisphere when the sun is north of the observer.

One or two examples in finding latitude from the meridian altitude of the sun may be of service in illustrating the method:

On August 18, 1918, off Cape Ann, Massachusetts, in W. Long. 70°, the observed meridian altitude of the sun's lower limb was 60° 19′ S. Height of eye 20 feet, index correction +30″. What was the latitude?

Observed altitude..60°19′ S.	H. of E. 20 feet, Dip by Table 14, Bowditch.. −4′23″
Index correction... +30″	Refraction and parallax for 60°, Table 20B, Bowditch .... −30″
Sextant altitude....60°19′30″	−4′53″
Correction .... +10′57″	Semi-diameter, lower limb ....+15′50″
T.C.A. ....60°30′27″ S.	−4′53″
	Correction ....+10′57″

89°59′60″	W. Long. 70° = 4 h. 40 m., G.M.T., Declination at 4 h. 40 m., August 18, from Nautical Almanac, 13°13′24″ N.
−T.C.A. ....60°30′27″ S.	
Z.D. ....29°29′33″ N.	
Dec. ....13°13′24″ N.	
N. Lat. ....42°42′57″	

Example: On February 16, 1918, off Palm Beach, Florida, in W. Long. 80°, the observed meridian altitude of the sun's lower limb was 50°38′ S. Height of eye 35 feet. No index correction. What was the latitude?

Observed altitude..50°38′ S.	Dip for H. of E. 35 feet, Table 14, Bowditch.. −5′48″
Correction .... +9′43″	Parallax and refraction for 50°40′; Table 20B, Bowditch ..... −41″
T.C.A. ....50°47′43″	−6′29″
89°59′60″	Semi-diameter of sun.+16′12″
−T.A.C. ....50°47′43″ S.	−6′29″
Z.D. ....39°11′17″ N.	Correction .... +9′43″
Dec. ....12°26′06″ S.	Declination of sun February 16, 1918, at 5 h. 20 m. = 80° W. Long. in time:—S. 12°26′06″.
N. Lat. ....26°45′11″	

In order to obtain the latitude from a meridian altitude of the sun, you must know your approximate longitude, but this need not be accurate. For example, for several days around the summer and winter solstice, the declination changes so slowly that you need only know the day of the month to find your latitude correctly; and even when the declination is changing most rapidly at the vernal and autumnal equinoxes an error of 15° in the longitude would give an error of only 1′ in the latitude.

LATITUDE FROM MERIDIAN ALTITUDE OF A STAR

You can find the latitude from a meridian altitude of the stars or planets quite as readily as from the sun, but in working with stars, it is often impossible to get a good horizon excepting it be in moonlight, or within an hour after sunset, or before dawn. This disadvantage is, however, in some measure offset by there being about two dozen bright stars which are near the ecliptic and thus well suited for observation for latitude and longitude.

In working with stars, you must first find the approximate time at which the star will reach the meridian. The method for doing this can best be illustrated by an example: In 60° W. Longitude, what is the approximate local mean time at which Sirius (α Canis Majoris) comes to the meridian on March 20, 1918?

From page 96, American Nautical Almanac; G.M.T. of meridian transit of Sirius at Greenwich, March 1	8 h. 6 m.
Correction for March 20 (20 days) on page 97, American Nautical Almanac	−1 h. 15 m.
	6 h. 51 m.

G.M.T. of transit of Sirius at Greenwich, March 20	6 h. 51 m.
Correction for 60° W. Long. = 4 hours, from page 4, American Nautical Almanac........	−0 m. 39 s.
Approximate local mean time of transit of Sirius, March 20, in 60° W. Long.	6 h. 50 m. 21 s.

Then, at about 6.40 P.M., we should begin to watch the change in altitude of the star just as we would in the case of the sun. Set your sextant to about 0° and look directly at the star with your telescope, and you will see two images of the star, one direct and the other reflected. Now push the index forward and keep the reflected image in view as it descends until it reaches the horizon. Then rock your sextant and get the correct altitude by means of the tangent screw. Look every now and then, each time bringing the star *down* to the horizon until it reaches its highest altitude. Then, when it begins to dip, leave your sextant alone and take the reading.

Suppose you found the observed altitude of Sirius to be 45°15′ S., height of eye 28 feet, and index correction +2′40″, what is the latitude?

Observed altitude.	45°15′ S.	Correction from Table 46, Bowditch, for H. of E. 28 feet, altitude 45°..	−6′09″
I.C.	+2′40″		
Sextant altitude..	45°17′40″		
Correction	−6′09″		
True altitude	45°11′31″ S.	Declination of Sirius from p. 95, Nautical Almanac S........	16°36′24″
	89°59′60″		
True altitude	45°11′31″ S.		
Z.D.	44°48′29″ N.		
Dec.	16°36′24″ S.		
N. Lat.	28°12′05″		

The altitude correction for stars is always subtractive, and there is no correction for semi-diameter, and the declination changes so slowly that one need not know the longitude or even the month of the year in getting the latitude.

LATITUDE FROM AN EX-MERIDIAN ALTITUDE OF THE SUN

When you first begin to observe the sun about 10 or 15 minutes before noon, you see that it rises rapidly at first and then more slowly until noon. Indeed, the change in altitude near noon is proportional to the square of the time from noon. Thus, if it is 1 minute from noon and the difference between the then altitude and the altitude the sun will have at noon is *a*, two minutes from noon the difference will be 4*a*, and in 3 minutes it will be 9*a*, etc. In other words, the decline in altitude both before and after noon is proportional to the square of the time from noon (at^2). The value of *a* is dependent upon your latitude, and the declination of the sun, and is given in Table 26, Bowditch, while at^2 is given in Table 27. We must, of course, always add this correction; for the altitude at noon is greater than at any time either before or after noon.

By using these tables, we can find our latitude from an observation made within 26 minutes before or after noon, but we must know our longitude quite accurately, and also our approximate latitude. Men-of-war use this method in order to report their position to the flagship exactly at noon.

Example: Off Cape Ann, Massachusetts, on August 31, 1918, in west longitude 70°38′; at Greenwich mean time 4 h. 27 m. 26 s.; the observed altitude of the sun *before* noon was 55°44′50″; height of eye 20 feet, index correction +30″; approximate latitude N. 42°38′, equation of time —24 s.; what was the exact latitude?

G.M.T. of observation	4 h. 27 m. 26 s.
Equation of time	−24 s.
Greenwich apparent time	4 h. 27 m. 02 s.
W. Long. 70°38′ in time	4 h. 42 m. 32 s.
Time before local apparent noon...............	15 m. 30 s.

Observed altitude...	55°44′50″
Index correction....	+30″
Sextant altitude.....	55°45′20″
Correction	+10′56″
T.C.A.	55°56′16″

Correction for H. of E. 20 feet altitude 55° from Table 46, Bowditch, +11′01″−5″ = +10′56″.

Declination of sun at 4 h. 27 m., August 31, from American Nautical Almanac, N. 8°47′07″.

In Table 26, Bowditch, for declination 9°, same name as latitude, and N. Lat. 43°, the variation of altitude in one minute from meridian passage is 2.5″.

In Table 27, page 716, Bowditch, with a variation in one minute of 2.5″, and time 15 m. 30 s. before noon.

2.″ corresponds with	8′00″
0.5″ corresponds with	2′00″
Correction for altitude	+10′00″

T.C.A. before noon	55°56′16″ S.
Correction	+10′00″
Corrected altitude at noon........	56°06′16″ S.
	89°59′60″
–Corrected altitude	56°06′16″ S.
Z.D.	33°52′44″ N.
Sun's declination	8°47′07″ N.
N. Lat.	42°39′51″

EXAMPLES FOR PRACTICE

Off Cape Ann, Massachusetts, on August 18, 1918, before noon at G.M.T. 4 h. 37 m. 51 s. in W. Long. 70°30′, the observed altitude of the sun's lower limb was 60°15′; height of eye 25 feet, index correction +1′, approximate latitude N. 42°40′, declination of the sun N. 13°13′48″, and equation of time —3 m. 51 s.; what is the exact latitude? *Answer:* N. Lat. 42°44′22″.

In Great Bay, New Jersey, on November 2, 1918, after noon, at G. M. T. 5 h. 04 m. 20 s. in W. Long. 74°24′, the observed altitude of the sun's lower limb was 35°26′40″; height of eye 36 feet; index correction +30″; approximate latitude 39°; declination of the sun S. 14°37′36″, and equation of time +16 m. 20 s.; What was the exact latitude? *Answer:* N. Lat. 39°30′18″.

EX-MERIDIAN $\phi''\phi'$ METHOD FOR FINDING LATITUDE

There is still another method, called the $\phi''\phi'$, by means of which we can find the latitude at the time of our observation, provided it be within three hours before or after noon. We must, however, have a good knowledge of our longitude, and the method is inaccurate if the declination of the sun is less than 3°. This method has the advantage that you need not know the latitude, but, on the other hand, you must know your longitude accurately. The process may be illustrated by the following example:

Off Eastern Point, Gloucester, Massachusetts, August 31, 1917, in west longitude 70°40′ at Greenwich mean time 5 h. 33 m. 59 s., the observed latitude of the sun's lower limb, after noon was 54°05′30″ S. Height of eye 20 feet; index error 0; what is the latitude?

G.M.T.	5 h. 33 m. 59 s.
Equation of time	−18 s.
G.A.T.	5 h. 33 m. 41 s.
W. Long. 70°40′ in time	4 h. 42 m. 40 s.
Hour angle, in time, after noon	51 m. 01 s. = 12°45′15″ by Table 45, Bowditch
Observed altitude	54°05′30″
Correction for H. of E. 20 feet, altitude 54°, from Table 46, Bowditch.	+10′51″
True central altitude	54°16′21″
Declination, August 31, at 5 h. 34 m.	8°40′46″ N.

Hour Angle (H. A.) 12° 45′ 15″	Log secant.. .01085, from Table 44, Bowditch		
Declination 8° 40′ 46″	Log tangent 9.18372	Log cosecant	.82128
Altitude 54° 16′ 21″			
ϕ'' 8° 53′ 43″ N.		Log sine	9.90945
ϕ' 33° 43′ 20″ N.	Log tangent 9.19457	Log sine	9.18932
N. Lat. 42° 37′ 03″		Log cosine	19.92005

We use Table 44, Bowditch, and add the logarithmic secant of the hour angle to the log. tangent of the declination and the sum is the log. tangent of ϕ''. Mark ϕ'' N. or S. to accord with the declination. Now look up the logarithmic cosecant of the declination, the sine of the altitude, and the sine of ϕ''. Add these and the sum is the logarithm of the cosine of ϕ' which we look up in Table 44. Mark ϕ' N. or S. to accord with the zenith distance. Now add or substract ϕ'' and ϕ', according to their signs, and the result is the latitude. We will have more to say respecting the use of Table 44 when we discuss the method of finding longitude.

LATITUDE FROM THE POLE STAR

Table I, page 107, of the American Nautical Almanac gives a convenient method for finding latitude within about 3 miles, from a time-sight of the pole star. Unfortunately, this star is not very bright and the horizon under it is usually poorly illuminated even on moonlight nights. All you have to do, however, is to find the true altitude of the pole star, and the local sidereal time of your observation, and then Table I at once gives you a correction to be applied to the altitude to obtain the approximate latitude.

Example: On October 10, 1918, in W. longitude 75°, at Greenwich mean time 10 h. 54 m.; the true altitude of Polaris was 26° 18′. What was the latitude?

EXAMPLES IN FINDING LATITUDE BY EX-MERIDIAN $\phi'' \phi'$ SIGHTS OF THE SUN

No.	Date	G. M. T. h. m. s.	Longitude	Observed Alt. of lower limb	H. of E. in feet	Index correction	Approximate latitude	Sun's declination	Equation of time	Answers
1	Sept. 4, 1917	3 56 40	W. 70° 40′	50° 03′ 50″ S.	25	+30″	43° N.	N. 7° 14′ 48″	+ 0m. 58s.	N. Lat. 42° 37′ 13″
2	Aug. 18, 1917	4 07 55	W. 70° 37′	59° 10′ 40″ S.	25	+30″	43° N.	N. 13° 09′ 28″	− 3m. 47s.	N. Lat. 42° 39′ 12″
3	Sept. 15, 1917	3 47 53	W. 70° 40′	48° 45′ 50″ S.	25	+30″	43° N.	N. 3° 05′ 28″	+ 4m. 44s.	N. Lat. 42° 35′ 58″
4	Nov. 2, 1917	5 4 36	W. 74° 25′	35° 26′ 40″ S.	36	+30″	39° N.	S. 14° 43′ 50″	+16m. 21s.	N. Lat. 39° 23′ 41″
5	Feb. 18 1918	6 12 36	W. 81° 40′	52° 46′	40	+30″	24° N.	S. 11° 43′ 24″	−14 m. 07 s.	N. Lat. 24° 31′ 51″

G.M.T.	10 h. 54 m.	October 10
Right ascension of the mean sun, Oct. 10, from page 2, Nautical Almanac	13 h. 13 m. 7 s.	
Correction for 10 h. 54 m., page 2, Nautical Almanac	+1 m. 38 s.	
Greenwich sidereal time	24 h. 08 m. 45 s.	October 10
W. Long 75° in time	5 h.	
Local sidereal seconds	19 h. 08 m. 45 s.	October 10

Correction from Table I, page 107, American Nautical Almanac for 19 h. 9 m.	+7′12″
True altitude	26°18′
Latitude N.	26°25′12″

On June 10, 1918, at Greenwich mean time 15 h. 36 m. 30 s., in W. Long. 74°; the true altitude of Polaris was 39°46′. What was the latitude?

G.M.T.	15 h. 36 m. 30 s.
R.A.M.S. June 10	5 h. 12 m. 07 s.
Correction for 15 h. 36 m.	2 m. 34 s.
Greenwich sidereal time (G.S.T.).....	20 h. 51 m. 11 s.
W. Long. 74° in time.................	–4 h. 56 m.
Local sidereal time (L.S.T.)..........	15 h. 55 m. 11 s.

Correction from Table I, page 107, Nautical Almanac....	+55′
True altitude of Polaris	39°46′
N. Lat.	40°41′

This last example is taken from page 107 of the American Nautical Almanac wherein, however, the time of observation is given as local astronomical mean time 10

h. 40 m. 30 s., whereas we commonly use Greenwich mean time in taking observations at sea.

LATITUDE FROM STARS AT MERIDIAN TRANSIT BELOW THE POLE

In the polar regions, we can find the latitude by getting the true central altitude of the sun, moon, or stars at meridian transit *below* the pole, and then adding the polar distance of the heavenly body observed. The polar distance (P.D.) is simply the angular distance of the heavenly body from the pole, and we can calculate it by subtracting the declination of the star from 90°.

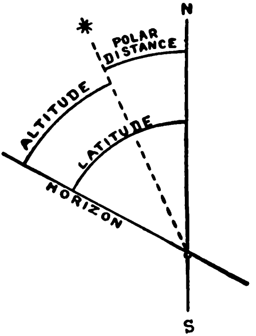


FIGURE 55. LAT.= P.D.+ALT.

FIG. 55.—Method of finding latitude from a lower meridian transit of a star below the pole.

The reason for this will appear upon an inspection of Fig. 55, where Lat. = Alt. + P.D.

To find the approximate time of lower meridian transit, take the Greenwich mean time of the previous upper transit at Greenwich from pages 96 and 97 of the American Nautical Almanac and add 11 h. 58 m. to it.

For example: What is the approximate local mean time of lower transit of Dubhe (α Ursa Majoris) on October 5, 1918, in W. Long, 13°30′?

G.M.T. of upper transit of Dubhe (α Ursa Majoris), Oct. 1, 1918, at Greenwich, from American Nautical Almanac, p. 96	22 h. 17 m.	
Correction for October 4, 1918; 4 days	−12 m.	
G.M.T. upper transit at Greenwich, Oct. 4	22 h. 05 m.	
Add for succeeding lower transit ...	11 h. 58 m.	
	34 h. 03 m.	October 4
G.M.T. lower transit of Dubhe, Oct. 5, at Greenwich	10 h. 03 m.	October 5
Correction for 13°30′ W. Long. = 54 m.	−9 s.	
Approximate local time of lower tiansit of Dubhe on Oct. 5, in W. Long. 13°30′	10 h. 02 m. 51 s.	

Accordingly, at about 9.50 P. M., local time, October 5, we would begin to watch the star with the sextant, and get the *lowest* altitude, which will, of course, be that of lower transit. Suppose the true altitude was 30°20′. What is the latitude,

Declination of α Ursa Majoris from page 95, Nautical Almanac	N. 62°11′12″
Polar distance of α Ursa Majoris = 90° − declination	27°48′48″
True altitude	30°20′
N. Lat.	58°08′48″

In the arctic regions in summer we can apply this method to the sun, and thus find our latitude at midnight.

PROBLEMS IN FINDING LATITUDE FROM MERIDIAN ALTITUDE OF THE SUN.

No.	Date 1917	Observed meridian altitude of sun's lower limb	Height of eye in feet	Index correction	Approximate longitude	Declination of the sun	Answer latitude	Geographical position
1	July 22	48° 15′ S.	25	−1′ 3″	W. 30°	N. 20° 20′ 06″	N. 61° 56′ 23″	Between Greenland and Iceland.
2	Sept. 25	52° 16′ 20″ S.	25	−1′ 40″	E. 15° 30′	S. 0° 42′ 54″	N. 36° 52′ 06″	Mediterranean, near Sicily.
3	Feb. 2	70° 20′ 40″ N.	16	+30″	W. 50°	S. 16° 51′	S. 36° 18′ 08″	ESE. of Buenos Ayres, South America.
4	June 21	89° 48′ S.	16	0	W. 70°	N. 23° 27′	N. 23° 27′	NW. of Bahamas.
5	Dec. 22	42° 54′ S.	16	0	W. 70°	S. 23° 27′	N. 23° 27′ 56″	NW. of Bahamas.
6	Jan. 4	67° 01′ S.	36	+1′ 20″	E. 150°	S. 22° 48′ 24″	Equator	N. of Bismark Archipelago.
7	June 1	88° 54′ 50″ S.	40	+2′ 10″	E. 60°	N. 21° 59′ 42″	N. 22° 52′ 55″	Mouth of Perisan Gulf
8	May 3	35° 10′ S.	20	+2′ 30″	W. 19° 40′	N. 15° 35′ 36″	N. 70° 13′ 08″	E. coast of Greenland.
9	Dec. 8	54° 40′ 20″ N.	36	−1′ 40″	E. 70° 30′	S. 22° 41′	S. 57° 52′ 50″	Off Cape Horn.
10	Oct. 13	42° 46′ 30″ S.	30	−1′	W. 74° 10′	S. 7° 44′ 25″	N. 39° 20′ 25″	Off Atlantic City, New Jersey.

EXAMPLES IN CORRECTION OF ALTITUDE

1. Correct. Observed altitude of sun's lower limb 31°40′50″. Index correction -2′20″. H. of E. 30 feet.
   —*Answer:* 31°47′42″.
2. Observed altitude of sun's lower limb 88°10′30″. Index correction -2′30″. H. of E. 100 feet. —*Answer:* 88°14′10″.
3. Observed altitude upper limb of sun 28°10′. Index correction +5′. H. of E. 20 feet. —*Answer:* 27°52′57″.
4. Observed altitude lower limb of sun 0°. Index correction +1′20″. H. of E. 16 feet.
   —*Answer:* -22′55″. The sun has a negative altitude because it is actually below the horizon. Refraction causes it still to appear above the horizon.
5. Observed altitude upper limb of sun 0°. Index correction +1′20″. H. of E. 16 feet. —*Answer:* -54′55″.

CHAPTER VIII.

LONGITUDE FROM THE SUN.

ON any day such as April 2, when the mean sun comes to the meridian at any place such a *G.*, Fig. 56, it is April 2, 0 h. 0 m. 0 s. astronomical mean time at that place; or April 2, 12 o'clock noon civil time. But the sun appears to move westward at the rate of 15° per hour, so we also measure time to the westward, and thus 5 hours after noon, the sun comes to the meridian at *P.*, 75° west of *G.* It is now astronomical time April 2, 0 h. 0 m. 0 s. at *P.*, and April 2, 5 hours, or 5 P.M. at *G.* Also, when it was noon at *G.*, it was 5 hours before noon at *P.*; or April 1, 19 hours astronomical time and 7 A.M., April 2, civil time.

Now, if *G* were Greenwich and *P* Cape May, New Jersey, we see that the difference in longitude between the two places is 5 hours, or simply the difference in their local times. A clock keeping local time in Greenwich is always 5 hours later than one keeping local time at Cape May, and this tells us that Cape May is $15° \times 5 = 75°$ west of Greenwich.

Indeed, astronomers prefer to state longitude in terms of hours, minutes and seconds, but navigators, who use charts, prefer to state it in degrees, minutes and seconds of arc, the longitude of Greenwich being 0° by general consent.

Looking again at Fig. 56, we see that when the sun is 5 hours west of Greenwich it makes an angle of 75° with the Greenwich meridian; so we say its *hour angle* is 5 hours west of Greenwich. We may, however, measure hour angles either east or west of the meridian. For instance, if the sun had come around so as to be over E. Long. 75°, as in Fig. 57, the time at Greenwich would be April 2, 19 hours, astronomical, or April 3, 7 A.M., civil time, and the hour angle 5 hours east. Thus for P.M. hours, the hour angle is the same as the local time, but for A.M. hours we must subtract the local time from 24 hours to find the hour angle.

To still further illustrate longitude, in Fig. 58 let G be Greenwich, and P a place 75° west of Greenwich. Then, when it is 8 h., April 2, at Greenwich, it is 3 h. April 2, astronomical time at P.

A more complicated case is shown in Fig. 59, where the time at P is 21 hours, April 2, while that of Greenwich is 2 hours, April 3. If, however, we express the Greenwich time as 26 hours, April 2, we bring both times to the same day, and see at once that their difference is 5 hours, corresponding with 75° difference in longitude.

Our ship's chronometer keeps Greenwich mean time, so if we could determine the exact time of local noon, we could at once find the longitude. Unfortunately, this is a difficult matter, for there is so little change in the sun's altitude for about 2 minutes on either side of the meridian that we cannot determine the instant of noon

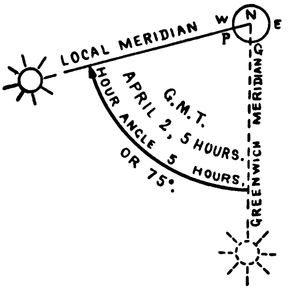


FIGURE 56.

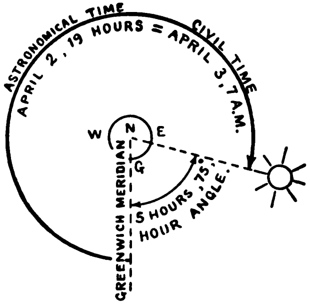


FIGURE 57.

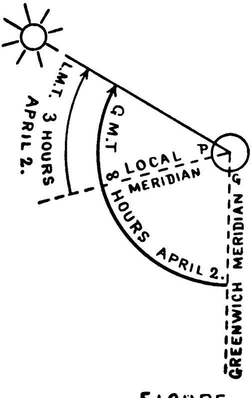


FIGURE 58

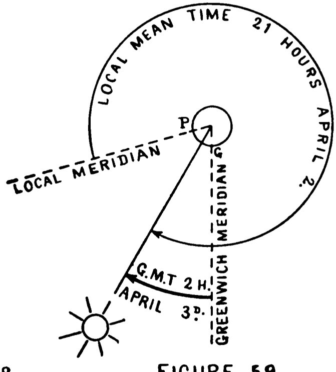


FIGURE 59.

FIG. 56.—Showing that when it is noon in 75° W. longitude, it is 5 hours past noon at Greenwich.

FIG. 57.—Showing the relation between astronomical and civil time and the relation between the astronomical time and the hour angle of the sun in the morning.

FIG. 85.—Showing that the difference in longitude between any two places is expressed by the difference in their local times.

FIG. 59.—Showing how longitude may be determined when the sun is east of some place in west longitude, but west of Greenwich. In other words, when it is morning in the place in west longitude but afternoon at Greenwich.

with a sufficient degree of accuracy, for an error of one minute in time would give 15′ error in longitude.

There is, however, one way out of the difficulty, and that is to take equal altitudes both before and after noon. Set your sextant and take the exact Greenwich mean time at which the lower limb of the sun comes to the horizon about half an hour before noon, then without changing the setting of the sextant, record the time when the lower limb again touches the horizon as it descends after noon. The average will evidently be the Greenwich mean time of local apparent noon, and by applying the equation of time, you find the Greenwich mean time of local mean noon and hence the longitude. For example:

Somewhere in west longitude, on February 16, 1918, the G.M.T. of contact of sun's lower limb with horizon

before noon was:	4 h. 40 m. 06 s.
and the G.M.T. of contact of sun's lower limb *after* noon was	5 h. 28 m. 30 s.
	2) 10 h. 08 m. 36 s.
G.M.T. of *apparent* noon	5 h. 04 m. 18 s.
Equation of time for G.M.T., 5 h. on Feb. 16	−14 m. 15 s.
G.M.T. of mean moon	4 h. 50 m. 30 s.
W. Long. from Table 45, Bowditch.......	72°30′45″

This method is inaccurate, due chiefly to the motion of the ship, and to a slight degree to the change in declination of the sun during the period between contacts. Also, being near noon, the contact between the sun and the horizon is at an oblique angle and is difficult to determine accurately; but it might be used by a hydro-aeroplane at rest upon the sea, and by reading the sextant after the first contact, then getting the noon altitude, and finally re-setting the sextant to its original reading, one could find both latitude and longitude.

The complex correction required when the ship is in motion renders this method of no advantage over others to be presently described.

The best method for finding longitude at sea is from a time-sight of the sun. If possible, this should be made when the sun is at least one and one-half hours before or after noon, or, better, when it bears due east or west from the ship; although to insure the greatest accuracy, the altitude should be at least 20°.

In the morning, bring the image of the sun's lower limb slightly below the horizon, and watch it ascend, rocking the sextant to insure a vertical altitude. Then at the instant the sun's lower limb comes up to the horizon, note the time either by glancing at a watch held in the palm of your left hand, or by stopping a stop-watch. The latter method is the more accurate, for it has the advantage that your attention is not distracted by attempting to observe *both* altitude and time at the same instant.

Wait until the second hand of your chronometer comes to an even minute, then start the stop-watch and note the chronometer time. The stop-watch then marks seconds in accord with the chronometer, so all you have to do when you stop the stop-watch is to add its reading to that shown by the chronometer when you set your watch going.

If we do not have a stop-watch we must use the old-fashioned method, and carry an ordinary watch in the palm of the left hand, and observe it at the instant the sun's lower limb touches the horizon. Read the seconds first, then minutes and hours. The watch time usually does not accord with the chronometer, and it is the practice of the Navy to call the difference C–W, C being the time shown by the chronometer at the instant the watch shows the time to be W. Suppose, for example, the chronometer indicated 5 hours, when the watch showed 2 hours. Then C–W = 3 hours, and if an observation were made at watch time 6 hours the chronometer time would be $6 + 3 = 9$ hours. Also in the Navy they commonly subtract watch time from chronometer time even if one must add 12 hours to the reading of the chronometer. Thus, suppose the watch showed 5 hours when the chronometer indicated 2 hours; then $2 + 12 - 5 = 9$ hours = C–W, and if such a watch indicated 6 hours the corresponding time on the chronometer would be $6 + 9 - 12 = 3$ hours; but the use of a good stop-watch avoids all these complications, and also gives a more accurate reading.

Every ship of any size or importance should have at least three chronometers, so that if one becomes irregular the other two will probably hold their rates. Chronometers must be protected from salt spray or dampness, and placed in as undisturbed a situation as the ship affords, well away from the vibration of engines or shock of gun-fire.

Above all, if you move the chronometer, do not give it a sudden horizontal twist. Wind it at 8 A.M. each day, and maintain it cool, and at a uniform temperature, by keeping it in a wooden box lined with insulating cloth. You must know the rate of your chronometer, and having ascertained this, you may make out a table for its correction on successive days, but remember that the rate is liable to change. For example: A chronometer on May 2, 1918, was slow on Greenwich mean time 4 m. 31 s., and its rate was fast 1.2 s. per day. What was its correction on June 28, 1918?

Gain due to 57 days at 1.2 s. per day = 68.4 s. Hence the chronometer was still 3 m. 22.6 s. slow on June 28, and we must add this to its reading to obtain Greenwich mean time.

LONGITUDE FROM A TIME-SIGHT OF THE SUN

If we know our latitude, and the sun's declination, there is a definite relation between the altitude of the sun and the local apparent time which enables us to find the latter by applying a rather complex formula. Then you convert the Greenwich mean time of the observation into Greenwich apparent time, and find the difference between this and the local apparent time, and the result is the longitude expressed in terms of time, which you may convert into arc by using Table 45, Bowditch.

We may illustrate the process by a few simple examples: On April 13, 1918, in west longitude, a P.M. sight of the sun's lower limb at Greenwich mean time 9 h. 58 min., gave a true central altitude 31° in N. Lat. 20° What was the longitude?

Greenwich mean time (G.M.T.)......	9 h. 58 m.	April 13
Equation of time	−35 s.	
Greenwich apparent time (G.A.T.)....	9 h. 57 m. 25 s.	

The declination of the sun April 13, at G.M.T. 10 h., was N. 9°, and the polar distance (P.D.) was (90°−9°) or 81°. The polar distance is taken from the pole nearest the observer, and as the latitude in this case is north, the polar distance is taken from the North Pole. If the declination had been 9° S., the polar distance would have been 99°.

Polar distance	81°	Log cosecant .00538, from Table 44, Bowditch.
Latitude	20°	Log secant .02701
Altitude.............	31°	
Sum................	2) 132°	
½ Sum.............	66°	Log cosine 9.60931
−Altitude	31°	
Remainder	35°	Log sine 9.75859
Log sine² ½ Hour angle		19.40029
Log sine ½ Hour angle		9.70014

Hour angle from Table 44, p. 802, Bowditch, for P.M. time is 4 h. 0 m. 44 s. In P.M. time, the hour angle is identical with the local apparent time (L.A.T.).

G.A.T..............	9 h. 57 m. 25 s.
L.A.T..............	4 h. 00 m. 44 s.
Longitude in time..	5 h. 56 m. 41 s. = W. Long. 89°10′15″ from Table 45.

Instead of using table 44 to find the hour angle, we could have looked up 19.40029 and found 4 h. 00 m. 43 s. in Table 45, page 859, Bowditch, which gives log. haversines (log. sine^2 of ½ angles) in terms of time, and also of arc. In the case just cited, there is a difference of 1 second between the hour angles found in Tables 44 and 45, but Table 45 gives the more accurate result, so that the better answer is W. Long. 89°10′30″.

Another simple example in *east* longitude ·om an *A.M.* sight of the sun is as follows:

In east longitude on November 13, 1918, an A.M. sight of the sun's lower limb was taken at G.M.T. 14 h. 45 m., giving a true central altitude of 24° in north latitude 22°. What was the longitude?

G.M.T.	14 h. 45 m.
Equation of time	+15 m. 37 s.
G.A.T.	15 h. 00 m. 37 s.

Declination Nov. 13, 1917, at G.M.T. 15 h., was 18° S. Polar distance 108°.

P.D.	108°	Log cosecant .02179, p. 790, Bowditch, top of column.
Lat.	22°	Log secant .03283
Alt.........	24°	
Sum	2)154°	
½ sum.....	77°	Log cosine 9.35209
–Alt.	24°	
Remainder..	53°	Log sine 9.90235
		Log sine² ½ hour angle 19.30906

From Table 45, page 853, Bowditch, we find that 19.30906 corresponds with L.A.T. 20 h. 25 m. 21 s. Subtracting G.A.T. *15 h. 00 m. 37 s.*, we have E. Long. in time 5 h. 24 m. 44 s = 81° 11′.

If the polar distance is greater than 90°, look up the cosecant at the bottom of the column in Table 44, and take the minutes of arc from the left-hand *M* column of the table. Thus, on page 790, Bowditch, the cosecant of 108°9′ is .02216.

Remember that for A.M. sights, the hour angle is *not* the local apparent time; but to find this you must subtract the hour angle from 24 hours, or look the time up at once from the bottom of the columns of log.-haversines in Table 45. Always avoid calculations and use tables if you can do so, for thereby you will escape errors which might entail serious consequences. In P.M. sights, however, the hour angle is the same as the local apparent time, and may be looked up from the top of the columns in Table 45.

We must take the polar distance from the pole that is the nearer to the ship, but if we are on the Equator we could use either pole, as is illustrated in the following simple example:

On the Equator on June 10, 1918, at G.T.M. 8 h. 47 m. 54 s. a P.M. sight of the sun gave a true central altitude of 43°. What was the longitude?

G.M.T.	8 h. 47 m. 54 s.
Equation of time......	+52 s.
G.A.T.	8 h. 48 m. 46 s.

Declination June 10, 1918, is 23° N., and as Lat. is 0°, we may take the polar distance as *either* 67° or 113°.

ALTERNATIVE SOLUTIONS

P. D.	67°	Log cosecant	.03597
Lat.	0°	Log secant	.0000
Alt.	43°		
Sum	2)110°		
½ Sum	55°	Log cosine	9.75859
−Alt.	43°		
Remainder	12°	Log sine	9.31788
Log sine^2 ½ hour angle.....			19.11244

Hour angle (H. A.) = L. A. T. for P.M. sight = 2 h. 48 m. 46 s. from Table 45, p. 844, Bowditch.

G. A. T.............	8 h. 48 m. 46 s.
L. A. T.............	2 h. 48 m. 46 s.
W. long. in time.....	6 h. 00 m. 00 s.

W. Long 90°. In Pacific west of Equador.

P. D.	113°	Log cosecant	.03597
Lat.	0°	Log secant	.0000
Alt.	43°		
Sum	2)156°		
½ Sum	78°	Log cosine	9.31788
−Alt.	43°		
Remainder	35°	Log sine	9.75859
Log sine^2 ½ hour angle.....			19.11244

PRELIMINARY LONGITUDE PROBLEMS

No.	A.M. or P.M. sight of sun	Astronomical date	Greenwich mean time h.	m.	s.	True central altitude	Declination of sun	Latitude	Equation of time	Longitude
1	P.M.	Sept. 10, 1917	4	57		47°	5° N.	30° N.	+ 3 m.	W. 37° 51′ 45″
2	A.M.	Nov. 21, 1918	22			19°	20° S.	18° N.	+ 13 m. 58 s.	W. 34° 38′ 30″
3	A.M.	Sept. 7, 1918	17	51		40°	6° N.	10° N.	+ 2 m. 3 s.	W. 41° 7′ 30″
4	P.M.	Nov. 3, 1917	1	44	57	45°	15° S.	12° N.	+ 16 m. 16 s.	E. 6° 16′ 30″

The formula we have been using in these examples is a fundamental one in navigation, but is so complex that it may not be profitable to attempt to derive it in an elementary book such as this, and it will perhaps suffice if we give it in the form of a simple statement: Suppose we let

$$S = \frac{\text{Alt.} + \text{Lat.} + \text{P.D.}}{2}$$

Also, let H.A. stand for the hour angle the sun makes with our meridian at the time of our observation. Then:

$$\text{Sine}^2 \tfrac{1}{2} \text{ H.A.} = \text{cosecant P.D.} \times \text{secant Lat.} \times \text{cosine S.} \times \text{sine (S. -Alt.)}$$

Or, using logarithms and remembering that when we multiply quantities we add their logarithms:

$$\text{Log. sine}^2 \tfrac{1}{2} \text{ H.A.} = \text{Log. cosecant P.D.} + \text{Log. secant Lat.} + \text{Log. cosine S.} + \text{Log sine (S. Alt.)}.$$

We look up the logarithms of the cosecant P. D., secant latitude, cosine S, and sine (S.-Alt.) in Table 44, Bowditch; add them and look up the sum in the log.-haversine column of Table 45, and read off the local apparent time from the top of the column for P.M. sights, or from the bottom of the column for A.M. sights. Then the longitude is simply the difference between our local apparent time and Greenwich apparent time.

Examples illustrating the use of Table 44, Bowditch, may be of service.

What is log. sine $14^\circ 19' 55''$?

Log sine 14° 19′ 9.39319
Opposite 55 in the left-hand "M" column, find in the "difference" column between columns A, A. .... +45
Log. sine 14°19′55″ 9.39364

What is log. cosecant 14°19′49″?

Log. cosecant 14°19′ .... .60681
Opposite 49 in left-hand "M" column, find in *Dif.* column between the A, A columns .... −40
Log cosecant 14°19′49″ .... .60641

For angles between 0° and 90° add the quantity found opposite the "M" column for sines, tangents, and secants; and *subtract* for cosines, cotangents and cosecants.

For angles between 90°–180°, however, do just the reverse; *subtract* the quantity opposite the left "M" column for sines, tangents, and secants, and *add* for cosines, cotangents, and cosecants. To illustrate: What is the cosecant of 104°38′44″

Log. cosecant 104°38′ .... .01432
Opposite 44 of left-hand "M" column in the Diff. column between the C, C columns .... +2
Log cosecant 104°38′44″ .... .01434

What is the log. cosine of 75°11′10″?

Log cosine 75°11′ 9.40778
Opposite 10 in the left-hand "M" column, find in the Diff. column between columns A, A .... −8
Cosine 75°11′10″ 9.40770

What is the log. cosine 104°49′34″?

Log cosine 104°49′ 9.40778
Opposite 34 of left-hand "M" column find .... +28
Log cosine 104°49′34″ 9.40806

We will now give a practical example in which the log. cosecant, secant and cosine may be looked up on page 786, Bowditch, which is here reproduced.

On November 1 1918, at Greenwich mean time 1 h. 56 m. 50 c., an A.M. sight of the sun gave a true central altitude of 32° 18′40″, in N. Lat. 14° 15′. What was the longitude?

G.M.T.	1 h. 56 m. 50 s.	November 1	
Equation of time	+16 m. 19 s.		
G.A.T.	2 h. 12 m. 09 s.	November 1	
Declination of sun	S. 14°17′42″		
Polar distance	104°17′42″		
P.D.	104°17′42″	Log cosecant	.01366
Lat.	14°15′	Log secant	.01357
Alt.	32°18′40″		
Sum	2) 150°51′22″		
½ Sum	75°25′41″	Log cosine	9.40070
–Alt.	32°18′40″		
Remainder	43°07′01″	Log sine	9.83473
Log. sine² ½ Hour angle			19.26266
L.A.T. from Table 45, page 851, Bowditch	20 h. 37 m. 20 s.	October 31	
G.A.T. 2 h. 12 m. 09 s., Nov. 1. = 26 h. 12 m. 09 s., October 31	26 h. 12 m. 09 s.	October 31	
L.A.T.	20 h. 37 m. 20 s.		
W. Long. in time	5 h. 34 m. 49 s.		
W. Long. from page 877, Table 45, Bowditch	83°42′15″		

In the Caribbean Sea, off the coast of Central America.

Longitude may be determined from a sunrise or sunset sight of the sun, although the result is uncertain, due

165°
M.
60
59
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Df.
75°

to the irregularities of refraction at low altitudes, and for this reason the method is rarely used. Due to refraction, the center of the sun is about 20′ below the horizon when the lower limb appears to touch the horizon, and about 52′ below when the upper limb disappears, and thus the altitude is negative. The sole advantage in this method is that one needs no sextant.

Example: On June 10, 1918, in N. Lat. 39°, at sunset, the sun's lower limb touched the horizon at Greenwich mean time 8 h. 47 m. 54 s. Height of eye 25 feet. What was the longitude?

G.M.T.	8 h. 47 m. 54 s.
Equation of time	+52 s.
G.A.T.	8 h. 48 m. 46 s.
Sun's declination	23° N.P.D. 67°

Dip. for H. of E. 25 feet	−4′54″
Refraction and parallax	−36′20″
	−41′14″
Semi-diameter of sun.	+16′14″
T.C.A.	−25′14″

P.D..	67°	Log cosecant .03507
Lat...	39°	Log secant .00665
	106°	
Alt.	−25′14″	
Sum ....2)	105°34′46″	
½ Sum	52°47′23″	Log cosine 9.90107
(−Alt.)	+25′14″	
Remainder......	53°12′37″	Log sine 9.90355
Log sine² ½ H.A.		19.84724 = 7 h. 36 m. 03 s.
G.A.T.	8 h. 48 m. 46 s.	
L.A.T.	7 h. 36 m. 03 s.	
W. Long. in time.	1 h. 12 m. 43 s.	
W. Long.	18°11″	

PROBLEMS IN FINDING LONGITUDE FROM TIME SIGHTS OF THE LOWER LIMB OF THE SUN

No.	Civil date	A.M. or P.M. sight	Chronometer reading h. m. s.	Chronometer fast or slow	Observed altitude of the sun's lower limb	Height of eye in feet	Index correction	Latitude	Declination of sun	Equation of time m. s.	Answer longitude
1	Nov. 1 1917	P.M.	7 47 26	Fast, 1m. 27s.	20° 59′ 30″	36	+30″	N. 39° 21′	S. 14° 27′	+16 20	W. 74° 25′
2	May 11, 1918	P.M.	13 20 06	Fast 2m., 50s	42° 18′ 30″	16	+1′ 30″	N. 26° 12′	N. 17° 53′	+ 3 46	W. 149° 30′ 15″
3	Nov. 7, 1918	A.M.	13 38	Slow, 6 sec.	32° 29′ 24″	25	+1′	S. 30° 12′	S. 16° 18′	+16 14	E. 90° 8′
4	April 16, 1918	A.M.	3 58 24	Slow, 3m. 10s.	22° 9′ 10″	28	−2′ 20″	S. 18° 10′	N. 9° 59′ 24″	+ 0 6	W. 122° 53′
5	Mar. 21, 1918	A.M.	20 7 31	Correct	Sunrise sight of lower limb	45	0	Equator 0°	S. 0° 2′ 24″	− 7 31	W. 30° 27′
6	Nov. 12, 1918	P.M.	20 5 10	Correct	Sunset sight of upper limb	16	0	N. 23° 29′	S. 17° 31′	+15 51	E. 137° 57′

At sea, we should endeavor to take a longitude sight when the sun bears true east or west. Usually, however, we cannot get a good determination of latitude until noon, and as we must know the latitude to determine longitude, it is the common practice not to work out the morning longitude sight until the latitude has been found at noon; then, knowing the course and speed of the ship, we calculate the latitude for the time of the morning sight and work out the longitude with this latitude; and finally, by dead reckoning find the longitude at noon, and thus get the position of the ship.

The following is an example for practice in this method:

On February 20, 1918, in N. Lat. 33°02′ at G.M.T. 2 h. 46 m., an A.M. sight of the sun gave an observed altitude of 32°07′50″. Index correction +1′30″. Height of eye 25 feet. Due to foggy weather the latitude was unknown, so the longitude could not be determined.

The ship then sailed 33 miles on a compass course NE. by N. Variation 4° W. Deviation 7° E. until noon when the observed altitude of the sun was 45°19′40″ S. Index correction +10″. Height of eye 25 feet. Declination of sun S. 11°01′24″. What was the latitude and longitude of the ship at noon?

Answer: N. Lat. 33°28′45″; W. Long. 76°38′.

CHAPTER IX

LONGITUDE FROM THE STARS

As we saw in the chapter on time, it is 0 h. 0 m. 0 s. local sidereal time when the first point in Aries comes to our meridian, just as it is 0 h. 0 m. 0 s. local mean time when the mean sun comes to the meridian.

The only essential differences between sidereal time and mean solar time are that mean solar time is measured by the westerly movement of the mean sun, and sidereal time is measured by the corresponding westerly movement of the first point in Aries. Also the mean solar day is about 3 m. 56 s. longer than the sidereal day, and as both are divided into 24 hours, the sidereal hour is nearly 10 seconds shorter than the mean solar hour.

As the sun appears to move eastward among the stars, the angular distance of the stars, sun, moon or planets is measured to the eastward from the first point in Aries, and is called *right ascension,* which is really only celestial longitude measured all around the heavens to the eastward, in terms of hours, minutes, and seconds.

A few diagrams may make these relations clear. In Fig. 60, let A represent the first point in Aries, S the mean sun, and P our place upon the earth, N being the North Pole, E east and W west.

Then, at the vernal equinox on March 22-23, there is an instant when the first point in Aries and the mean sun are both on the meridian at noon, and it is o h. o m o s., both in mean solar and in sidereal time, and the right ascension of the mean sun is also o h. o m. o s.

The sun appears, however, to move eastward with reference to the stars, so that a month after the vernal equinox the conditions are as shown in Fig. 61, where

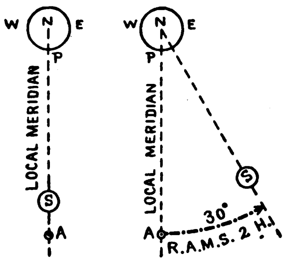


FIGURE 60. FIGURE 61.

FIG. 60.—Showing the sun and the first point in Aries on the meridian together at the March equinox. The right ascension of the sun is now o h. o m. o s.

FIG. 61.—Showing the position of the sun on April 23, one month after the vernal equinox when the sun has gone eastward 30° from the first point in Aries, and its right ascension is 2 hours.

the first point in Aries has come to our meridian and it is o h. o m. o s. local sidereal time; but the sun being in the east, it is only 22 hours of the previous astronomical day in mean solar time; and the right ascension of the mean sun is 2 hours, so when the sun comes to the meridian it will be 2 hours local sidereal time. Thus the local sidereal time at which any star comes to the meridian is simply the right ascension (R.A.) of that star.

Moreover, if a star has gone westward, say 3 hours beyond our meridian, the local sidereal time is the right ascension of the star plus 3 hours; and, conversely, if the star has not yet reached our meridian but is still east of it by 3 hours, the local sidereal time would be found by substracting 3 hours from the R.A. of the star. Thus to

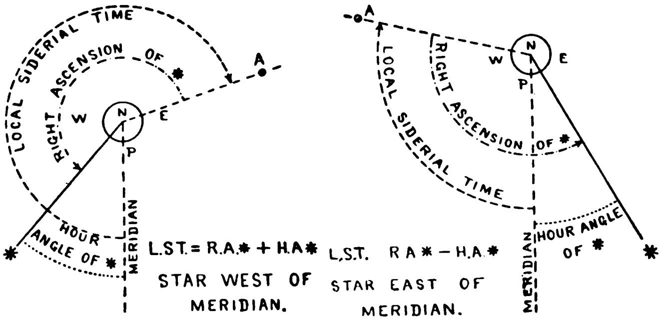


FIGURE 62. FIGURE 63.

FIG. 62.—Showing that when a star is west of the local meridian, the local sidereal time is the sum of the right ascension and the hour angle of the star.

FIG. 63.—Showing that when a star is east of the local meridian, the local sidereal time is found by subtracting the hour angle from the right ascension of the star.

find the local sidereal time, we must add the hour angle of the star to the right ascension if the star is west of the meridian (Fig. 62) and subtract it if east (Fig. 63).

But our ship's chronometer keeps Greenwich mean time in accord with the mean sun, and not with the stars, while if we observe the stars, we must use sidereal time, so we must convert Greenwich mean time into sidereal time.

Fig. 64 shows us that the Greenwich sidereal time is the sum of the Greenwich mean time and the right ascension of the mean sun; and, of course, local sidereal time is simply the sum of the local mean time and the right ascension of the mean sun, because Greenwich mean time is only the local time of Greenwich, and in no essential does it differ from the local time of any other place.

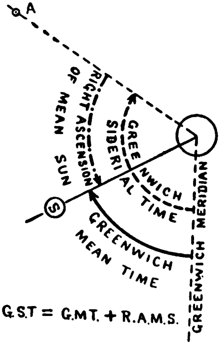


FIGURE 64.

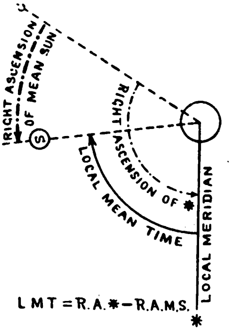


FIGURE 65.

Fig. 64.—Showing that the Greenwich sidereal time may be found by adding the Greenwich mean time to the right ascension of the mean sun.

Fig. 65.—Showing that local mean time may be found by subtracting the right ascension of the mean sun from the right ascension of a star on the local meridian.

Example: On July 5, 1918, in W. Long. 75° at Greenwich mean time 8 h. 48 m., what is the local sidereal time?

Greenwich mean time	8 h. 48 m.	July 5
Right ascension of the mean sun (R.A.M.S.) at Greenwich mean noon July 5, from American Nautical Almanac, p. 3................	6 h. 50 m. 41.2 s.	

Correction to convert 8 h. 48 m. mean time interval into sidereal time interval. Bottom of p. 2, Nautical Almanac	+1 m. 26.7 s.
Greenwich sidereal time (G.S.T.)....	15 h. 40 m. 07.9 s.
W. Long. 75° in time............	−5 h.
Local sidereal time (L.S.T.)........	10 h. 40 m. 07.9 s.

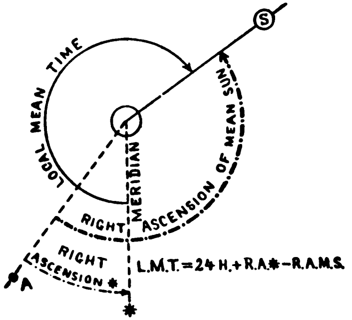


FIGURE 66.

FIG. 66.—Showing that if the right ascension of the sun is greater than that of the star on the meridian we must add 24 hours to the right ascension of the star, and then subtract the right ascension of the sun to find the local mean time.

Quite often we wish to know the exact time at which a star reaches our meridian and Fig. 65 shows us that the local mean time of meridian transit of a star may be found by subtracting the right ascension of the sun from the right ascension of the star. Also, if the R.A. of the star is less than that of the sun, add 24 hours to it, as shown in Fig. 66. An example showing the practice of the method follows:

In 60° W. Long. find the exact local mean time at which Sirius (α Canis Majoris) comes to the meridian on March 20, 1918.

On page 94, American Nautical Almanac..R.A. Sirius 6 h. 41 m. 34 s. on March 20.

When a star is on the local meridian, the local sidereal time is the same as the right ascension of the star. Hence the L.S.T. = 6 h. 41 m. 34 s.

R.A. of mean sun on March 20 at Greenwich mean noon, p. 2 of American Nautical Almanac	23 h. 48 m. 50 s.
Correction for 4 hours past noon; 4 h. = 60° W. Long.	+39 s.
R.A.M.S. (right ascension of the mean sun)...	23 h. 49 m. 29 s.

The right ascension of the star being less than that of the sun, add 24 hours to it.

R.A. of star +24 h.........................	30 h. 41 m. 34 s.
-R.A.M.S.	-23 h. 49 m. 29 s.
Sidereal time interval from mean noon......	6 h. 52 m. 05 s.
Correction for 6 h. 52 m. to convert sidereal time interval into mean time interval, p. 4, Nautical Almanac	-1 m. 07.5 s.
Local mean time of transit of Sirius........	6 h. 50 m. 57.5 s.

On page 115, we solved this example for the approximate local mean time of the star's meridian transit, using pages 96 and 97 of the American Nautical Almanac.

If we know our longitude and Greenwich mean time, we can easily find the hour angle of any star, for Figs.

62 and 63 show us that the hour angle is simply the difference between the local sidereal time and the right ascension of the star. If the right ascension is the greater, the star is east of the meridian, and if the local sidereal time is the greater, it has passed the meridian and is in the West. An example may help to make this clear: In west longitude 70° 15′, on April 20, 1918, at Greenwich mean time 11 h. 14 m. 30.2 s., what is the hour angle of Sirius?

G.M.T.	11 h. 14 m. 30.2 s.	April 20
R.A.M.S. at Greenwich mean noon, April 20....	1 h. 51 m. 02.9 s.	
Correction for 11 h. 14 m.	+1 m. 50.9 s.	
G.S.T.	13 h. 07 m. 24 s.	
70° 15′ W. Long. in time...	-4 h. 41 m.	
Local sidereal time.......	8 h. 26 m. 24 s.	
Right Ascension of Sirius from p. 94, Nautical Almanac..................	6 h. 41 m. 33 s.	
Hour angle of Sirius.....	1 h. 44 m. 51 s.	Star in the west.

In Chapter VIII, we saw that the longitude of any place is given by the difference between the local time of the place and the local time of Greenwich, and, of course, the two times must be expressed in the same system. That is to say:

West Longitude = {
- Greenwich mean time—Local mean time.
- Greenwich apparent time—Local apparent time.
- Greenwich sidereal time—Local sidereal time.

Thus, in observation of stars, we must use sidereal time, just as in observing the sun we used apparent solar time. The following table, covering all possible cases in star-sights, may be of service:

TABLE FOR CALCULATING LONGITUDE FROM TIME-SIGHTS OF THE STARS

Illustrated by	Star E. or W. of the local meridian	Right ascension of star greater than right ascension of sun	Right ascension of star less than right ascension of sun	West Long. = G. S. T. − L. S. T. East Long. = L. S. T. − G. S. T.
Figure 67	E. . .	. . . . + . .	. . . .	G.S.T. = G.M.T. + R.A.M.S. L.S.T. = R.A.* − H.A.*
Figure 68	E. . .	. . . .	. . . . + . . .	G.S.T. = G.M.T. + R.A.M.S. − 24 hours. L.S.T. = R.A.* − H.A.*
Figure 69	W. . .	. . . . + . .	. . . .	G.S.T. = G.M.T. + R.A.M.S. L.S.T. = R.A.* + H.A.*
Figure 70	W. . .	. . . .	. . . . + . . .	G.S.T. = G.M.T. + R.A.M.S. − 24 hours. L.S.T. = R.A.* + H.A.*

G.M.T. = Greenwich mean time.
G.S.T. = Greenwich sidereal time.
L.S.T. = local sidereal time.
R.A.M.S. = right ascension of mean sun.
H.A.* = hour angle of star.
R.A.* = right ascension of star.

The table and figures may seem complex, but are fundamentally simple, for all we have to remember is that if the star in the *east, subtract* its hour angle from its right ascension to find local sidereal time. If it is in the *west, add* its hour angle to its right ascension. Also, if the right ascension of the star is *less* than that of the sun, *add* 24 hours to it, or *subtract* 24 hours from the

Greenwich sidereal time (G.M.T. + R.A.M.S.), as in the table. The latter is more logical but sometimes less convenient.

Example: On July 13, 1917, astronomical Greenwich

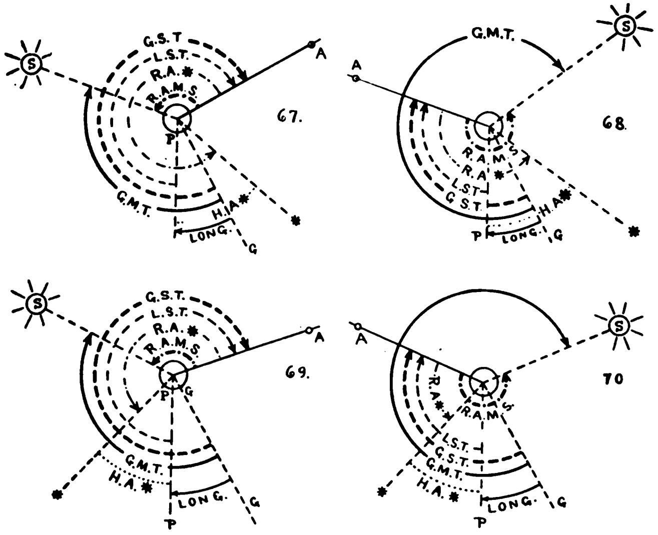


FIG. 67. G.S.T = G.M.T. + R.A.M.S.
L.S.T. = R.A.* − H.A.*

FIG. 68. G.S.T. = G.M.T + R.A.M.S − 24 H.
L.S.T. = R.A.* − H.A.*.

FIG. 69. G.S.T.= G.M.T. + R.A.M.S.
L.S.T. = R.A.* + H.A.*

FIG. 70 G.S.T. = G.M.T + R.A.M.S.− 24 H.
L.S.T. = R.A.* + H.A.*.

LONG. = G.S.T. ~ L.S.T.

FIGS. 67, 68, 69 and 70.—Illustrating the method for finding longitude from time-sights of the stars. In Figs. 67 and 68, the star is east of the meridian; and in Fig. 67, the right ascension of the star is greater than that of the sun, while in Fig. 68 the right ascension of the star is less than that of the sun. In Figs. 69 and 70 the star is west of the meridian; and in Fig. 69 the right ascension of the star is greater while in Fig. 70 it is less than that of the sun.

mean time 22 h. 33 m. 50 s., the true altitude of Jupiter in the east was 40°17′01″, in N. Lat. 24°38′. What was the longitude?

G.M.T.	22 h. 33 m. 50 s.	July 13
R.A.M.S. at noon Greenwich, July 13	7 h. 23 m. 11 s.	
Correction for 22 h. 33 m.	+3 m. 42 s.	
G.S.T.	30 h. 00 m. 43 s.	July 13
G.S.T.	6 h. 00 m. 43 s.	July 14
R.A. Jupiter	4 h. 04 m. 08 s.	Declination of Jupiter
N. 19°56′10″	Polar distance 70°03′50″	

P.D.	70°03′50″	Log. cosecant	.02684
Lat.	24°38′	Log. secant	.04144
Alt.	40°17′01″		
Sum........2)	134°58′51″		
½ Sum....	67°29′25″	Log. cosine	9.58301
Alt.	40°17′01″		
Remainder.	27°29′24″	Log. sine	9.66426

Log sine² ½ H.A. ....19.31555 = 3 h. 36 m. 23 s.

R.A. Jupiter..	4 h. 04 m. 08 s.	G.S.T.	6 h. 00 m. 43 s.
H.A. in East.	−3 h. 36 m. 23 s.	L.S.T.	27 m. 45 s.
L.S.T.	27 m. 45 s.	Long. in time.	5 h. 32 m. 58 s.
		W. Long. 83°14′30″, near Tortugas, Florida.	

In the example above, the right ascension of the planet was less than that of the sun, so we *subtracted* 24 hours from the Greenwich sidereal time, but we could equally well have added 24 hours to the right ascension of Jupiter. The planet being in the east, we *subtracted* its hour angle from its right ascension to find the local sidereal time.

We will now consider a sight of Aldebaran in the west taken by William K. Nimick, Esq., U.S.N., on the practice cruise of the Princeton University naval unit:

On February 16, 1918, in N. Lat. 25°24′, the ship's chronometer indicated 13 h. 54 m. Chronometer slow on Greenwich 8 m. 38 s. Observed altitude of Aldebaran in the west 61°30′50″. Index correction —2′20″. Height of eye, 26 feet. Declination of star N. 16°20′48″, right ascension 4 h. 31 m. 15 s. What was the longitude?

Chronometer	13 h. 54 m.	
Correction	+8 m. 38 s.	
Greenwich mean time	14 h. 02 m. 38 s.	February 16
R.A.M.S. February 16, at Greenwich, mean noon	21 h. 42 m. 40 s.	
Correction for 14 h. 02 m........	2 m. 18 s.	
G.S.T.	35 h. 47 m. 36 s...	February 16
G.S.T.	11 h. 47 m. 36 s.	February 17

Observed Alt.*......	61°30′50″	Correction for H. of E. 26 feet and Alt. 60° from Table 46, Bowditch, -5′34″
I.C.	-2′20″	
Sextant Alt.	61°28′30″	
Correction	-5′34″	
True altitude........	61°22′56″	

Declination of Aldebaran N. 16°20′48″. Polar distance 73°39′12″.

P.D.	73°39′12″	Log. cosecant	.01792
Lat.	25°24′	Log. secant	.04415
Alt.	61°22′56″		
Sum..............2)	160°26′08″		
½ Sum	80°13′04″	Log. cosine	9.23020
-Alt.	61°22′56″		
Remainder	18°50′08″	Log. sine	9.50901
Log sine² ½ H.A.			18.80128

H.A.*	1 h. 56 m. 33.5 s. in the west
R.A.*	4 h. 31 m. 15 s.
L.S.T.	6 h. 27 m. 48.5 s.
G.ST.	11 h. 47 m. 36 s.
W. Long. in time	5 h. 19 m. 47.5 s.
W. Long.	79°56′52″

Straits of Florida, between Carysfort and Fowey's Rock Light House.

In this case, the star is in the west so we add its hour angle to its right ascension to find the local sidereal time. Also, as the right ascension of the star is less than that of the sun, we subtract 24 hours from the Greenwich sidereal time.

On June 18, 1918, astronomical Greenwich mean time 14 h. 40 m. 20 s., in N. Lat. 27°40′, the true altitude of Antares (α Scorpii) was 30°10′ in the east. What was the longitude?

G.M.T.	14 h. 40 m. 20 s. June 18
R.A.M.S. at Greenwich mean noon, June 18	5 h. 43 m. 40 s.
Correction for 14 h. 40 m.	2 m. 24 s.
G.S.T.	20 h. 26 m. 24 s.

Declination of Antares S. 26°15′12″, P.D. 116°15′12″.

P.D.	116°15′12″	Log cosecant	.04728
Lat.	27°40′	Log secant	.05273
Alt.	30°10′		
Sum	2)174°05′12″		
½ Sum	87°02′36″	Log cosine	8.71251
-Alt	30°10′		
Remainder	56°52′36″	Log sine	9.92298
Log sine² ½ H.A.	=		18.73550

H.A.*	1 h. 47 m. 53 s. in the east
R.A.*	16 h. 24 m. 27 s.
L.S.T.	14 h. 46 m. 34 s.
G.S.T.	20 h. 26 m. 24 s.
W. Long. in time............	5 h. 39 m. 50 s. = W. Long. 84°57′30″

Off Tampa Bay, Florida.

In this example the star is in the east, so we subtract its hour angle from its right ascension to obtain the local sidereal time. Also the right ascension of the star is greater than that of the sun, so we do not subtract 24 hours from the Greenwich sidereal time.

EXAMPLES FOR PRACTICE

On February 14, 1918, in N. Lat. 33°15′ at Greenwich mean time 11 h. 20 m. 01 s., observed altitude of Sirius in the east 24°50′. Index correction +30″. Height of eye 22 feet. Right ascension of mean sun at Greenwich mean moon, Feb. 14, 21 h. 34 m. 47 s. Right ascension of Sirius 6 h. 41 m. 34 s. Declination of Sirius S. 16°36′24″. What was the longitude? Sight taken by Messrs. Beal and Mather, U.S.N., practice cruise of Princeton University naval unit.

Answer: W. Long. 77°55′45″.

On February 20, 1918, in N. Lat. 35°25′ the observed altitude of Jupiter in the west was 19°18′20″. Index correction +3′10″. Height of eye 28 feet, at Greenwich mean time 16 h. 23 m. 13 s. Right ascension of the mean sun at Greenwich mean moon Feb. 20, 21 h. 58 m. 26 s. Right Ascension of Jupiter 4 h. 02 m. 28 s. Declination of Jupiter 20°06′36″. What was the longitude? Sight taken by George K. McIlwain, U. S. N., Princeton University naval unit practice cruise.

Answer: W. Long. 75°16′30″.

CHAPTER X

SUMNER LINES OF POSITION

HAVING learned how to find the latitude and longitude of the ship, we will now consider the full significance of our observations, for by so doing the most accurate method for finding our position at sea will be revealed.

In Fig. 71 we see a side view of the earth in summer when the sun is north of the Equator. The polar axis (N–S), the sun (S) and our meridian are all supposed to be in the plane of the paper so it is noon on the meridian in the plane of the paper.

Then, at the point A, which is at the sun's declination north of the Equator, the sun is vertically overhead and its altitude is 90°. Anywhere north or south of A the altitude is less than 90° and steadily declines 1′ for every nautical mile we depart from A. This decline in altitude is caused by the curvature of the earth, and not by our looking at the sun from different angles, for the sun is so far distant that AS, BS and CS are all parallel and meet at the center of the sun 92,500,000 miles away. We see, also, if AB = AC, the altitude of the sun at B, is the same as its altitude at C, excepting that at B the sun is south of the zenith while the ship at C sees it to the northward of the zenith. The altitude at B and C are similar solely because these places are both at equal distances from the sun's vertical point A; and this would be true whatever their direction from the point A. There is, therefore, a circle around the point A—at every point on which the altitude of the sun is the same, although its bearing differs, dependent upon our position on the circle. In fact, along any circle drawn around the vertical point A as a center, the altitude is constant; so whatever our altitude we are always upon the arc of a circle of

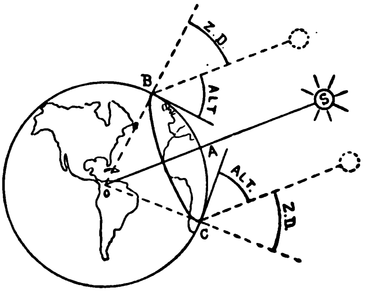


FIGURE 71.

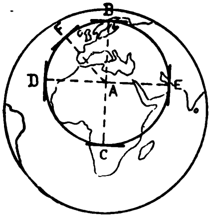


FIGURE 72.

FIGS. 71 and 72.—Illustrating a circle of equal altitude.

equal altitude, the center of which is at the sun's declination north or south of the Equator.

We could thus find our position if we knew the true compass bearing of the sun, and our distance from the sun's vertical point. The true bearing of the sun is called the *azimuth,* and is given for every 10 minutes of the day in Publication No. 71 of the U. S. Hydrographic Office; so if we know our local apparent time, we can at once find the azimuth.

Inspection of Fig. 71 will show that if O be the center of the earth, the angle AOB is the zenith distance. Of course, the zenith distance is simply 90° –altitude, and this gives us the distance AB in angular measure, so that knowing 1′ to be a nautical mile we could at once find AB in nautical miles by converting the zenith distance into minutes of arc.

This method for finding one's position at sea is not used, because a slight error in the azimuth would make a considerable difference in our position on the circle due to the great length of the radius, AB, in most cases; but as we will soon see, a modification of this method has been ingeniously devised by Admiral Marc St. Hilaire to enable us to find our approximate latitude and longitude.

But to return to a consideration of the circle of equal altitude, we see that its radius is usually so great, being 60 nautical miles for every degree we depart from the sun's vertical point, that a short length of the circle is practically a straight line.

Thus if we found our latitude and longitude by any method, and also knew the azimuth of the sun, we could at once draw a line through our position perpendicular to the direction of the sun's azimuth and we would be on that line as is illustrated by Fig. 72, where we have simply moved our point of view so as to look straight down upon the circle of equal altitude instead of seeing it in side view, as in Fig. 71.

We now see that for a short distance, say 30 miles, on both sides of the position B, the arc of the circle of equal altitude practically coincides with the perpendicular to the azimuth line BA; and this is true whatever the azimuth, as appears at C, D, E, F, or any other place on the circle.

This fact was discovered by Captain Thomas H. Sumner in 1837, and is one of the most important advances in navigation, for it shows us that we are not only at an isolated point but also on a line of position, as it is called. All we have to do is to find our latitude and longitude and througn the point thus found draw a perpendicular to the azimuth line of the sun and this perpendicular is our line of position. In other words, it is more probable that we are somewhere on this line of position than that we are at the exact point indicated by our observations.

Inspection of Fig. 72 at once shows us why it is desirable to take our sight for longitude when the sun bears east or west, for at D, where the azimuth of the sun is east, our line of position runs north and south, and thus we might make a considerable error in our latitude but our longitude would be correct. The same applies to E, from which place the sun bears west.

Similarly, at B or C the sun bears south or north, so the lines of position run east and west and thus we might make a decided error in our longitude, but our latitude would be correct, so we take a noon sight for latitude, and a *prime vertical* (E. or W.) sight for longitude.

At F, on the other hand, the azimuth is about SE., so our line of position extends NE.–SW., and any error in latitude makes a corresponding error in longitude, but nevertheless, if we calculated our longitude with any of these wrong latitudes we would still find positions on our *line of position,* and this shows that we are always more certain we are on the line of position than that we are at any definte point on that line.

Now suppose we had two stars, one bearing SE. and the other SW. and we took longitude sights on both at, as nearly as possible, one and the same time, we would get two lines of position and of each we could say we are more certain that we are on this line than at any single point upon it; therefore, the most probable position of the ship is at the intersection of the two lines of position. We have thus fixed the position of the ship by astronomical cross-bearings.

A modification of this method may be used with the sun while the ship is in motion and is illustrated in Fig. 73. In the morning, take a longitude sight, using an assumed latitude which, let us say, places the ship at A. Now draw the line of position AA′ perpendicular to the azimuth of the sun, and note the log and course of the ship. Then, in the afternoon, after we have sailed say ENE. 25 miles, take another longitude sight with another assumed latitude, giving the position B and line of position BB′. Then, with your parallel rulers, run off a line ENE. 25 miles from AA′ and parallel to it, such as *PP′;* and where PP′ and BB′ intersect at (I) is the true position of the ship.

You could thus find your position even if you could not get the noon latitude, and were more or less uncertain of the latitude both at the morning and the afternoon sight.

The reason we are justified in drawing PP′ parallel with AA′, is that small parts of concentric circles close together are practically parallel even if not on the same radius, as shown in Fig. 74, where BB and CC are practically parallel, although not on the same radius.

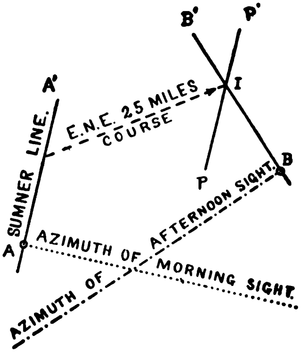


FIGURE 73.

FIG. 73.—Showing the method of finding the position of the ship from an intersection of two Sumner lines of position.

A great advantage in Sumner's method is that it is a graphic process which you may plot on your chart, thus showing the relation of the ship's course and position to all possible dangers.

Indeed, the most certain course you can make is to sail on your line of position as was done by Captain Sumner, according to the description given on page 150, Bowditch. Of course, Sumner's method may also be used with a morning longitude and a noon latitude sight, as is shown in Fig. 75. Here we work out our morning sight for longitude with an assumed but somewhat uncertain latitude, and note the course and speed of the ship. Sup-

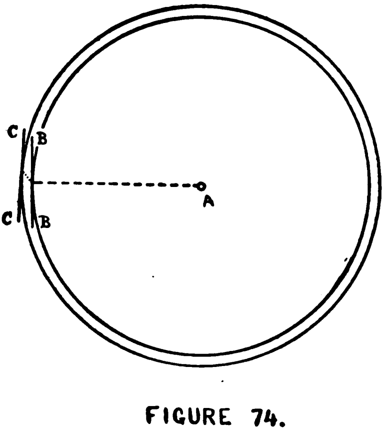


FIG. 74.—Showing that tangents to two concentric circles, close together, are essentially parallel even though not exactly upon one and the same radius.

pose you find the position A and line of position AA′ for the morning sight of the sun. Then, at noon, you get the latitude of the ship and find yourself to be somewhere on a line BB′ drawn on a parallel of latitude. Now knowing your course to have been NE. and distance 20 miles, lay off PP′ parallel with AA′, and you are at (I) where it intersects BB′.

We can most readily find the azimuth by looking it up in the U. S. Table of Azimuths of the Sun, or in the case of stars, in the Table for Azimuths of Celestial Bodies, whose Declinations range from 24° to 70°; Publication No. 120, U. S. Hydrographic Office.

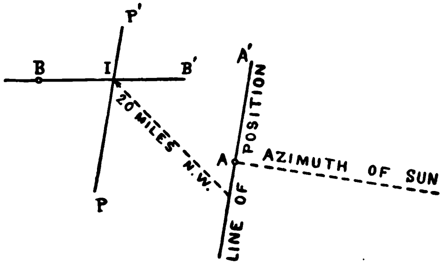


FIGURE 75.

FIG. 75.—Showing the use of Sumner lines with a morning longitude and noon latitude.

If, however, you do not have an azimuth table, you may calculate the azimuth as in the following example:

On June 10, 1918, in N. Lat. 10° at Greenwich mean time 7 h. 15 m., a P.M. sight of the sun gave true central altitude 43°. What was the longitude, azimuth of the sun, and line of position?

G.M.T.	7 h. 15 m.
Equation of time	+52 s.
G.A.T.	7 h. 15 m. 52 s.

Declination of sun 23° N. Polar distance 67°.

Longitude		
P. D.	67° Log cosecant	.03597
Lat.	10° Log secant	.00665
Alt.	43°	
Sum	2)120°	
½ Sum	60° Log cosine	9.69897
−Alt.	43°	
Remainder	17° Log sine	9.46594
Log sine^2 ½ H. A.		19.20753
	=3 h. 9 m. 25 s.	
G. A. T.	7 h. 15 m. 52 s.	
L. A. T.	3 h. 09 m. 25 s.	
Long. in time	4 h. 6 m. 27 s.	
W. Long.	61° 36′ 45″	

Azimuth of the Sun		
P. D.	67°	
Lat.	10° Log secant	.00665
Alt.	43° Log secant	.13587
Sum	2)120°	
½ Sum	60° Log cosine	9.69897
−P. D.	67°	
Remainder	− 7° Log cosine	9.99675
Log cosine^2 ½ azimuth		19.83824
Log cosine ½ azimuth		9.91912
½ azimuth		33° 53′
Azimuth N. 67° 46′ W.		

The azimuth is westerly in the afternoon and easterly in the morning.

The line of position is perpendicular to the azimuth, and thus runs N. 22° 14′ E.-S. 22° 14′ W. We would then draw the line of position through the point on the chart indicated by N. Lat. 10°, W. Long. 61°36′45″.

In Fig 76, we may illustrate the use of Sumner lines of position by the following example: On June 22, 1917, in an unreliable dead reckoning N. Lat. 17°50′, at Greenwich mean time 1 h. 21 m. 39 s., the true central altitude of the sun was 48°08′30″. The ship then sailed 25 miles N. 40° E. and at noon the true central altitude of the sun was 84°53′ N., in dead reckoning W. Long. 64°. What was the true position at noon by Sumner's method?

Working out the morning longitude with the unreliable latitude N. 17°50′, declination N. 23°27′, and equation of time −1 m. 39 s., gives us local apparent time 21 h. 02 m. 01 s., June 21; and W. longitude 64°29′45″. The azimuth table for this declination and local apparent time gives the azimuth of the sun N. 75°20′ E. Thus the Sumner line of position extends N. 14°40′ W. through the position N. Lat. 17°50′. W. Long. 64°29′45″.

The noon altitude gives N. Lat. 18°20′ in dead reck-

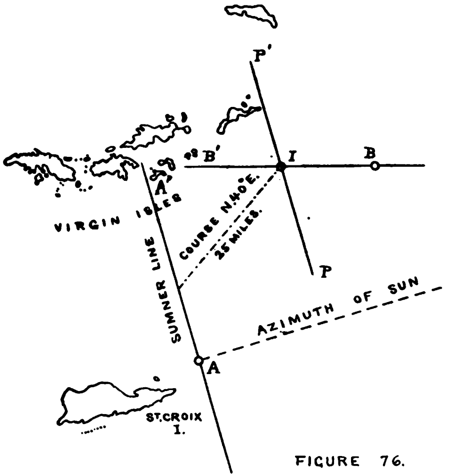


FIG. 76.—Illustrating the use of Sumner lines with a morning longitude calculated with an uncertain latitude, and a noon latitude calculated with an uncertain longitude.

oning W. Long. 64°, and of course the Sumner line for local apparent noon runs E–W.

In Fig. 76, A is the position calculated from the morning longitude sight with the assumed latitude N. 17°50′, and B the position from the noon latitude sight with the assumed longitude 64°. A is actually nearly 12 miles too far south, and B is 16′ too far east, yet if our course was N. 40° E., 25 miles, we see we must be at I where PP′, which is parallel with the Sumner line AA′ intersects the parallel of latitude BB′. Thus, according to the chart, our true position is N. Lat. 18°20′, W. Long. 64°16′; and this is probably nearly correct despite the fact that we were 12 miles in error in our latitude in the morning and nearly 16 miles in error in our longitude at the noon sight.

CHAPTER XI

ST. HILAIRE'S METHOD

CAPTAIN SUMNER had no azimuth tables, but he surmounted the difficulty by assuming two latitudes, one a few miles north and the other somewhat south of his most probable place. Then taking a time sight and finding the altitude of the sun, he used each latitude with this altitude to calculate a corresponding longitude, and finally he drew the line of position through the two places thus determined.

Most of the examiners for master's licenses in the Merchant Marine still insist on this laborious and clumsy method, but it is far better to calculate a single longitude, using your observed altitude, and most probable latitude, and through the place on the chart thus found draw the line of position perpendicular to the azimuth line of the sun.

There is, however, an even simpler way by which you can improve your dead reckoning, and this we owe to Admiral Marc St. Hilaire, of the French Navy.

In common with many ingenious inventions, its underlying principle is extremely simple. In Fig. 77, let the meridian and the sun be in the plane of the paper, and let the sun be in north declination. Then at A, which is at the sun's declination north of the Equator, the sun is vertically overhead, and its altitude is 90°. As we depart from A, in any direction, the altitude declines and if we were at B, which is 10° away from A, the altitude would be 80°, while at C, which is 15° away from A, it is 75°. The distance between B and C is therefore (80°–75°) ×60, or 300 miles, because a minute of arc in latitude on the surface of the earth is a nautical mile.

Now imagine your dead reckoning latitude and longitude led you to suppose you were at B, and you had a way for calculating the sun's altitude if you actually *were* at

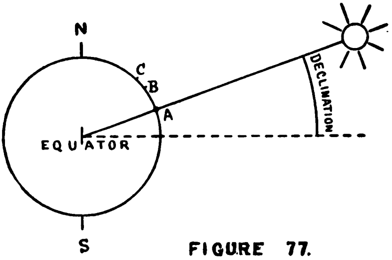


FIG. 77.—Illustrating the principle of St. Hilaire's method.

B, and this indicated the altitude should be 80° if the supposition that you were at B was correct. But if you *observed* the altitude and found it to be 75°, you would know you were (80°–75°) or 5° (300 miles) *farther away* from B than you supposed; and if you drew an azimuth line through A and B and extended it on your chart you would find your improved position at C 300 miles north of B. Of course, in practice, A is usually so far away from B that it is not on our chart, and we merely draw that part of the azimuth line which extends from B to C.

If the *observed* altitude is greater than the altitude corresponding to your assumed position, you would know at once that you were *nearer* the sun's vertical point than you thought you were, and you would therefore draw your azimuth line from your assumed position *toward* the sun's vertical point and lay off on this line an offset of as many miles as the difference in minutes of arc between your calculated and your observed altitude.

Of course the line from the ship to the sun's vertical point gives the true bearing of the sun, or azimuth, and while we have illustrated the case as it is at noon when the azimuth line passes due north and south, it will be evident that the same principle applies whatever the direction of the azimuth.

One can see that the direction of the azimuth changes even if the ship does not move; for the latitude of the sun's vertical point is at the sun's declination north or south of the Equator; and its longitude is in the plane of the noon meridian, as it passes westward around the earth; its exact position at any instant being given by the Greenwich apparent time.

Now we must find a method for calculating the sun's altitude for the latitude, longitude and hour angle of the place we think we are in, and then the difference in minutes of arc between this *calculated* altitude and the *observed* altitude will at once tell us how many miles our assumed position is in error, for if the observed altitude is less than the calculated altitude, we are farther away from the sun's vertical point than we thought, and our improved position lies on the azimuth line drawn from our assumed position away from the sun's vertical point.

To calculate the altitude of the sun corresponding to our assumed position, take the dead reckoning latitude and longitude, and find the hour angle corresponding to your time sight of the sun. Then if S = cosine Lat. $\times$ cosine Declination $\times$ haversine of the hour angle:

Natural haversine of zenith distance (Z.D.) = natural haversine (Lat. $\backsim$ Dec.) + natural haversine of S.

The symbol Lat. $\backsim$ Dec. means that we must subtract the less from the greater, and as the subtraction must be made algebraically by changing the sign of the subtracted quantity, we must take care to avoid mistakes thus:

Lat.	20° N., or +	Lat.	20° N., or +
Dec.	10° S., or —	Dec.	10° N., or +
Lat. $\backsim$ Dec.	30°	Lat. $\backsim$ Dec.	10°
Lat.	10° N., or +	Lat.	10° N.
Dec.	20° S., or —	Dec.	20° N.
Lat. $\backsim$ Dec.	-30°	Lat. $\backsim$ Dec.	10°

Negative angles need not trouble us, for the haversine of a negative angle is the same as that of the corresponding positive angle.

An example will serve to illustrate the method which is really much simpler than it seems from this complicated description:

On November 1, 1917, a P.M. sight of the sun at

Greenwich mean time 7 h. 45 m. 49 s. from the outer end of the Steel Pier at Atlantic City, New Jersey, gave a true central altitude of the sun 21°07′37″. Our position at the end of the Steel Pier was known to be N. Lat. 39°21′, W. Long. 74°22′30″; but in order to test the efficacy of St. Hilaire's method, let us assume that we were in W. Long. 74°, N. Lat. 39°10′, thus about 21 miles S. 58° E. from our actual position:

G.M.T.	7 h. 45 m. 49 s.
Equation of time Nov. 1	+16 m. 20 s.
G.A.T.	8h. 02 m. 09 s.
Assumed W. Long. 74° in time..............	−4 h. 56 m. 00 s.
Local apparent time ..	3 h. 06 m. 09 s. = hour angle for P.M. sight.

Hour angle.... 3 h. 06 m. 09 s.	Log haversine,	Table 45 = 9.19329
Assumed Lat. N. 39°10′	Log cosine,	Table 44 = 9.88948
Sun's declination ....S. 14°27′	Log cosine,	Table 44 = 9.98604
Lat. ∾ Dec. .. 53°37′	Log. S.	29.06881

Natural haversine S.........	.11716	from Table 45
Natural haversine .. 53°37′	.20341	from Table 45
Natural haversine of Zenith Distance..................	.32057	
Calculated Zenith Distance..	68°58′15″	from Table 45
Calculated Altitude (90° − Z.D.)	21°01′45″	
Observed Altitude..........	21°07′37″	

Offset, toward the sun's vertical point 5′52″

The sun's azimuth from Azimuth Table is N. 132° W.

Then laying off 5.86 miles N. 132° W. from our assumed position A_2, in N. Lat. 39°10′, W. Long. 74°, we get as our improved position N. Lat. 39°06′05″, W. Long. 74°05′36″. We are still about 20 miles from our actual position as is shown in Fig. 78, but

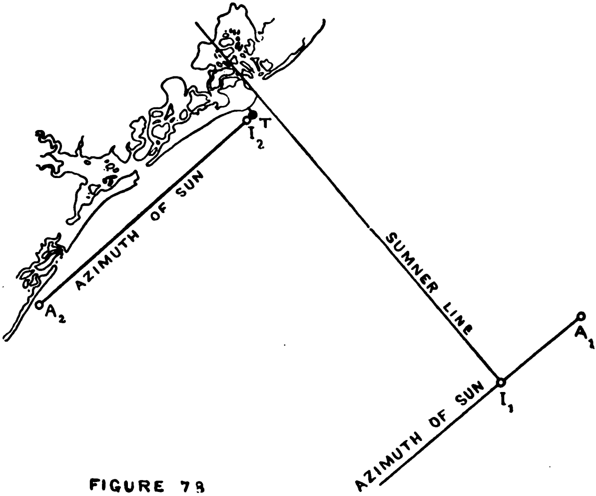


Fig. 78.—The Steel Pier at Atlantic City, illustrating the application of St. Hilaire's method. A, assumed position, I improved, and T the true position from which the observations were made.

if we draw the Sumner line through the improved position (I_2), we see that it passes within a mile of our actual position (T) at the end of the Steel Pier. In this example A_1 (Fig. 78) is the assumed, I_1 the improved and T the true position. It provides us with an illustration both of the strength and the weakness of St. Hilaire's method. It is unsurpassed for obtaining a Sumner line, but if our assumed position and our actual position happen to be far apart, but both on or near the Sumner line of position, it cannot appreciably improve our dead reckoning latitude and longitude.

Let us, however, try another case wherein our assumed and our true positions are both nearly on the azimuth line of the sun. For example, let us assume a position (A_2 Fig. 78) about 16 miles nearly SW. from the outer end of the Steel Pier, in N. Lat. 39°10′, W. Long. 74°40′; and then see what St. Hilaire's method does to improve our position.

Working the previous example in this new form, we have:

G.M.T.	7 h. 45 m. 49 s.
Equation of time	+16 m. 20 s.
G.A.T.	8 h. 02 m. 09 s.
Assumed W. Long. 74°40′ in time............	-4 h. 58 m. 40 s.
Local apparent time	3 h. 03 m. 39 s.

As it is a P.M. sight, the local apparent time is the hour angle (H.A.).

Hour angle....	3 h. 03 m. 39 s.	Log haversine,	Table 45 = 9.18219
Assumed Lat..	N. 39°10′	Log cosine,	Table 44 = 9.88948
Declination of Sun	S. 14°27′	Log cosine,	Table 44 = 9.98604
Lat. ∾ Dec...	53°37′	Log S.	29.05771

Natural haversine of S, from Table 45	.11421
Natural haversine Lat. Dec. 53°36′	.20341
Natural haversine of zenith distance (Z.D.)	.31762
Zenith distance (Z.D.) from Table 45	68°36′20″
Calculated altitude=(90°-Z.D)	21°23′40″
Observed altitude	21°07′37″
Offset 16 miles	16′03″

From the Azimuth Tables of the sun, publication No. 71 of the U. S. Hydrographic Office, we find the azimuth to be N. 132° W.

Evidently as our assumed position gave too high an altitude, we are farther away from the sun's vertical point by 16 miles N. 132° W.–N. 48° E.; so we lay off a distance of 16 miles N. 48° E. from our assumed position N. Lat. 39°10′; W. Long. 74°40′; and this places us in the improved position N. Lat. 39°20′15″ W. Long. 74°24′15″, as is shown in Fig. 78, wherein A_2 is our assumed, I_2 the improved, and T the true position. We have this time greatly improved our position, the final error being negligible while our assumed position was in error about 16 miles. This latter example shows us the advantage in taking a time sight of the sun for St. Hilaire's method when the sun's azimuth is in line with the course of the ship, and you know the latitude and longitude of some place on your course. For even if your assumed position is 50 miles or more in error, the improved position will be practically correct, provided no current has thrown your ship out in the direction of the Sumner line.

In fact, in using St. Hilaire's method, you may usually rely on the Sumner line you obtain, but not on your improved position; for in order to determine the latter you should get an intersection of two Sumner lines, with an interval of from 3 to 6 hours, if you sight upon the sun.

An example illustrating the process of solving a St. Hilaire problem when the Latitude and Declination are both north, may be of service.

Let us suppose that on June 22, 1917, we knew we were NE. of St. Croix, West Indies, in N. Lat. 17° 50′, W. Long. 64° 30′, but we assumed for the sake of testing St. Hilaire's method that we were in N. Lat. 17° 35′, W. Long. 64° 56′. Then if at Greenwich mean time 1 h. 21 m. 39 s., June 22, the true central altitude of the sun at an A.M. sight was 48° 08′ 30″; what is the improved position by St. Hilaire's method?

G.M.T.	1 h. 21 m. 39 s.		June 22
G.M.T.	25 h. 21 m. 39 s.		June 21
Equation of time	−1 m. 39 s.		
G.A.T.	25 h. 20 m. 00 s.		
W. Long. 64° 56′ in time.	4 h. 19 m. 44 s.		
L.A.T. .... June 21	21 h. 00 m. 16 s.	= H.A. 2 h. 59 m. 44 s.	
Hour angle A.M.	2 h. 59 m. 44 s.	Log. haversine	9.16446
Declination	N. 23° 27′	Log. cosine	9.96256
Latitude	N. 17° 35′	Log. cosine	9.97922
Dec. ∾ Lat.	5° 52′	Log. S.	29.10624

Natural haversine S....	.12771	
Natural haversine 5°52′.	.00262	
Natural haversine zenith distance........	.13033	Z.D. = 42°19′30″
Calculated altitude (90° −Z.D.)..............		47°40′30″
Observed altitude.....		48°08′30″
Offset northerly and easterly from the assumed position......		28′00″
Azimuth of sun from Table, N. 75° 20′ E.		

By dead reckoning, the improved position is N. Lat. 17°42′15″, W. Long. 64°27′33″, which is about 8 miles in error, but the Sumner line of position extends from this point N. 14°40′ E. and practically passes through our true position. On page 168, we worked this problem for Sumner lines, using the old-fashioned methods.

St. Hilaire's method is chiefly of advantage in that through the addition of 5 easily determined quantities we obtain the latitude and longitude of a point on a line of position, the direction of which is perpendicular to the azimuth. Its disadvantage lies in the fact that while you may feel fairly confident you are somewhere upon this line of position, you cannot be certain of your exact place upon the line. This disadvantage may, however, be overcome by obtaining two lines of position from two separate time sights, and fixing your place at the intersection of these two lines. Moreover, the process has the advantage that it practically obliges one to use graphic methods upon the chart.

If the observed altitude is more than 80°, it is well to draw an arc of the circle of equal altitude through the improved position with the sun's vertical point as its center and the zenith distance in minutes of arc as its radius.

EXAMPLES FOR PRACTICE IN ST. HILAIRE'S METHOD

1. At the outer end of the steel pier at Atlantic City, New Jersey, in N. Lat. 39°21′, W. Long. 74°22′30″, at Greenwich mean time 7 h. 37 m. 14 s., November 2, 1917, a P.M. time sight of the sun gave a true central altitude 22°06′05′. Assumed position N. Lat. 29°30′, W. Long. 74°10′. Equation of time +16 m. 22 s., Declination S. 14°45′, Azimuth of sun N. 132° W. What is the offset and the improved position by St. Hilaire's method?

   —*Answer:* Offset 13 miles. Improved position N. Lat. 39°21′, W. Long. 74°22′15″. Thus the assumed position is nearly 13 miles in error but the improved position is practically correct.

2. At Cape Ann, Massachusetts, in N. Lat. 42°36′, W. Long. 70°38′, on August 31, 1917, at Greenwich mean time 6 h. 45 m. 22 s., a P.M. sight of the sun gave a true central altitude 46°44′17″. Assumed position N. Lat. 42°40′, W. Long. 70°35′. Equation of time -16 s., Declination N. 8°39′46″, Azimuth of sun, N. 133°45′ W. What is the offset, and the improved position by St. Hilaire's method?

   —*Answer:* Offset 5.3 miles. Improved position N. Lat. 42°36′40″, W. Long. 70°39′15″.

CHAPTER XII

LIGHTS, RULES OF THE ROAD, AND SIGNALS

A VOLUME rather than a chapter should be devoted to these important subjects, but as every navigator must have a good practical knowledge of such matters, we should at least pay some attention to them. One should become thoroughly familiar with the Pilot Rules published by the United States Government, but a good epitome of the subject with instructive comments thereupon will be found in " Modern Seamanship," by Rear Admiral Austin M. Knight.

LIGHTS

Red, white and green lights, indicated in the following figures by Ⓡ, Ⓦ and Ⓖ. are the only ones commonly used by vessels; blue lights being for special signals not coming under the laws of the rules of the road.

Inland steamers, or boats propelled by machinery in harbors, carry the lights indicated by Fig. 79, A being a side view and B a view seen from above. There is a white light showing 20 points ahead on the fore-mast, or forward part of the vessel near the bow; and in range with this another white light, showing all around the horizon, is placed on the after-mast above all awnings, and at a higher level than the forward white light; but

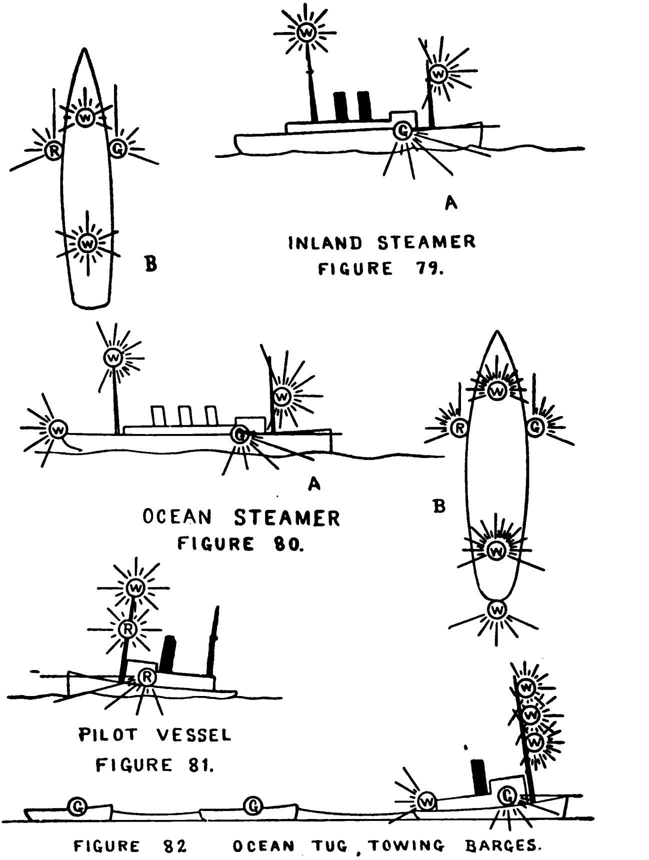


FIG. 79.—The system of lighting for an inland steamer.

FIG. 80.—Showing the arrangement of lights on an ocean steamer.

FIG. 81.—Illustrating the lights shown by a steam pilot vessel under way, and on her station.

FIG. 82.—Showing the lights carried by an ocean tug towing two barges.

the horizontal distance between these lights must be greater than the vertical distance. If the vessel is over 40 feet long there may be another white light placed usually on the taffrail aft and showing 12 points astern. Small vessels do not usually carry the stern light but keep a white lantern ready to show, should occasion require it.

In addition to these white lights there must be a green light on the starboard side showing through 10 points from dead ahead to 2 points abaft the beam; and on the port side there is a red light similarly arranged. These lights must be so protected by side boards that only one of them can be seen upon a side view of the boat and each side board must be painted of a color similar to the light at the main mast head.

Ocean steamers, Fig. 80, carry the same lights described above except that the range light on the after-mast usually shows ahead 20 points instead of all around the horizon, and when this is the case a stern light visible through 12 points is carried near the taffrail aft.

Sailing vessels carry only the green and red side lights, but may, should occasion demand it, show a white lantern from the stern; and yachts under both power and sail often carry only side lights, but they should carry the lights of steamers of their class and size.

Steam pilot vessels, when on their stations, carry a white light high up on the mast and vertically below this a red light, both being visible all around the horizon. They have also the usual green and red side lights, but when at anchor the side lights are extinguished while the white and red mast lights remain. By day a blue flag is carried at the main mast head.

A sailing pilot on her station shows a flare-up light at intervals of not more than fifteen minutes and she also carries a white top-mast light visible all around the horizon, and flashes her green and red side lights at intervals. If at anchor she shows the flare-up light, but not the red or green side lights.

Ocean tugs when towing have the green and red side lights carried by all vessels when under way, but in addition there are 2 or 3 white lights at least six feet apart, placed vertically one above the other, and visible through 20 points forward. When only one vessel is being towed, two white lights are shown, but if two or more barges are towed, or the tow is over 600 feet long, the tug shows 3 white lights in a vertical line. Harbor tugs show the same white lights, but they are visible all around the horizon. In addition there is a single white light placed low in the after part of the vessel and visible only from the stern for the towed vessel to steer by. Lights six feet apart appear as a single light if seen from a distance of four miles.

A steamer not under control, or aground in a fair way, or a suction dredge engaged in dredging, must carry two red lights at least six feet apart, visible all around; and vertically one over the other; and by day such a vessel shows two black balls similarly arranged. If moving through the water, the green and red side lights are displayed, but these are not shown if the vessel is aground, for then she uses the regular anchor lights in addition to the two red warning lights.

Vessels less than 150 feet long if at anchor carry one white light, visible all around the horizon, but if over 150 feet, they show two such lights, one forward and the other aft, and both above all awnings, for it is well to remember that a light under an awning has no significance as a signal. The forward light should be between 20 and 40 feet above the hull, and the stern light at least 15 feet lower than the forward light.

Vessels laying cables, anchored over divers, dredging or engaged in special services which restrict their movements, carry variously colored balls or shapes by day, and at night two red lights vertically arranged, or four lights in a vertical line, the upper and lower being white, and the middle ones red. The arrangement of these lights depends, however, on the nature of the service the vessel is engaged upon; but in general balls and shapes by day and two red lights one over the other at night are warning signals indicating that the vessel has certain rights of way; and must be avoided.

RULES OF THE ROAD

A vessel is under way when she is not anchored, moored to a wharf, or aground, and if backing she must govern herself as if the stern were her bow.

The rules of the road are remarkably simple; indeed, one might almost say there is only one rule: *If you turn, go to the right.* Let us, however, consider them case by case in order to grasp some of their significance. In the first place, we should have a clear idea of the meaning of certain terms derived from the remote past when vessels were steered by a tiller and not by the wheel. In the old parlance " port your helm " meant to push the tiller over to the left, or port side, of the vessel; thus causing the bow to turn to the right, or starboard.

The United States Navy avoids this ambiguity, however, by referring to the rudder, and not to the tiller. Thus " right rudder " means that the rudder is turned to the right and the bow of the vessel also turns to the right, or starboard. Wheels are usually made so that a turn toward the port side, or anticlockwise, as you face the bow, causes the bow to swing to starboard; but others are direct in their action, a starboard turn of the wheel giving a starboard turn to the bow. In all cases, however, when going forward, "right rudder" turns the bow to the starboard, and " left rudder " turns the bow to port, as is shown in Fig. 83.

One blast of the whistle means, " I direct my course to starboard "; two blasts, " I direct my course to port," and three blasts, " my engines are going full speed astern." At least four short sharp " snorts " is a warning or protesting signal. None of these signals must be given unless the vessels are actually in sight of each other, and never in a fog when neither ship can see the other.

The simplest situation is when two steamers are approaching " dead ahead " from opposite directions so that the masts and funnels of the one are in line with the masts

FIGURE 83

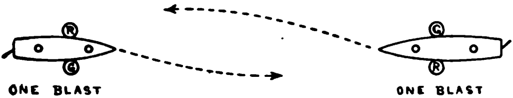


FIGURE 84.

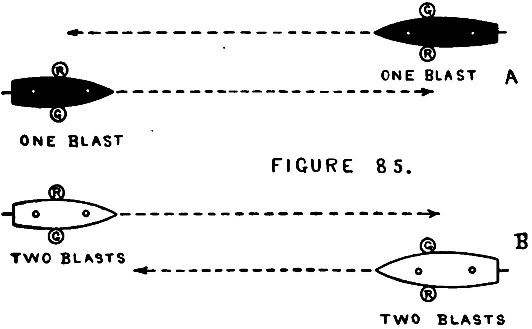


FIGURE 85.

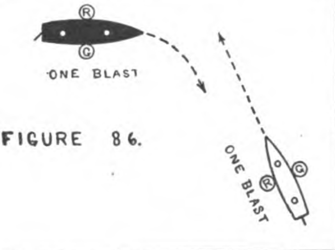


FIGURE 86.

87.

FIG. 83.—Showing effect of right rudder and left rudder when moving forward.
FIG. 84.—Showing the procedure of two steamers approaching head on.
FIG. 85.—Steamers approaching on parallel courses not involving risk of collision.
FIG. 86.—Illustrating the rule of the road when two steamers approach in a slanting direction.
FIG. 87.—The danger area is dotted in the diagram. Vessels approaching within this area must be avoided.

and funnels of the other, or by night both the red and the green lights of each are seen by the other. One vessel gives a single blast of its whistle which must be answered by a single blast from the other vessel, and then each gives right rudder thus directing the course to its own starboard side, and passing the other vessel port side to port side, or red light to red light as seen at night.

At sea this is the only way in which two steamers approaching dead ahead may legally pass each other; but in inland waters one of the vessels may, provided no other signals have been exchanged, give two blasts, and if these be answered by two blasts from the other vessel, she may then give left rudder, go to the left, and pass the other vessel, which may hold its course or also go to port. This case is illegal, however, and the vessel giving the initial two blasts assumes the responsibility for any accident, nor would it be permitted at sea under any circumstances, and even in harbors it should be avoided. The only legal way in which to pass is stated in the ancient doggerel:

> "When both lights you see ahead
> Port your helm and show your red,
> One blast upon your whistle blow
> Sight his red, and let her go."

Another simple situation is shown in Fig. 85, A and B, wherein two steamers are approaching on parallel courses not involving risk of collision. In case A each vessel is on the port bow of the other so at night each would probably see only the red light of the other, or the red light would be more distinct than the green. One of the vessels gives one blast of its whistle and the other must answer by one blast and each holds its course and they pass port side to port side.

In case B, Fig. 85, on the other hand, the green light of each is seen from the other, and each vessel is thus on the starboard bow of the other. One vessel gives two blasts which must be answered by two blasts from the other vessel and each holds its course, so that they pass starboard side to starboard side, or green light to green light. This is the only case in which two blasts are legally recognized as a direction signal at sea, and they simply mean, "I intend to hold my course," or, as the rhyme has it:

"Green to green or red to red,
Hold your course and go ahead."

A third and very important case is shown in Fig. 86, wherein the black steamer sees the red light of the other one approaching in a slanting direction on the starboard bow; and the white steamer sees the green light of the other on its own port bow. Now a steamer has the right of way over other steamers approaching on its own port side so the white vessel gives one blast anl then holds its course and speed, while the black one must answer by one blast, give right rudder and pass the other astern even if she must slow down, stop, or reverse engines to do so. The vessel which has the other on its own port side must hold its course and speed, while the one which has the other on its own starboard side must keep out of the way of the other by directing its course to starboard.

Thus you have right of way over steamers approaching on your own port side and this *obliges* you to hold your course and speed unless you can prevent an otherwise inevitable collision by acting differently. It is often an awkward situation to be in for practically the entire responsibility for avoiding a collision rests with the other vessel.

On the other hand, if you are a steamer you nave no right of way over any vessels approaching you on your starboard side from dead ahead to two points abaft the starboard beam, as shown in the dotted area of Fig. 87, so cultivate the habit of frequently casting your eye over this area.

If the bearing of an approaching vessel does not change, you know there is danger of collision and must act accordingly.

A following vessel, even if she is a sailing vessel, has no right of way over any vessel she is following. By a following vessel we mean one approaching from a position more than two points abaft the beam of the vessel ahead.

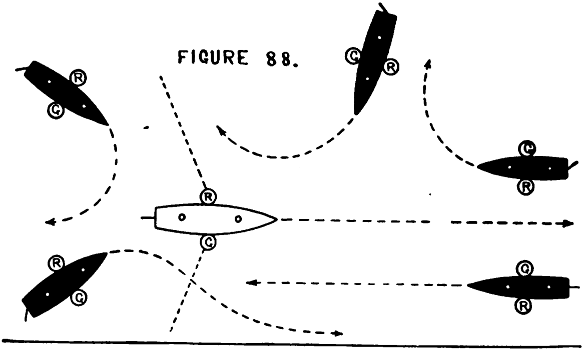
A following vessel in a narrow channel may give one blast, and if this be answered by one blast from the vessel followed, she may give right rudder and pass to starboard of the followed vessel; or she may give two blasts and if replied to by two blasts, she may then pass to port; but if the vessel which is being followed fails to reply, or replies by warning signals, the following vessel must not attempt to pass, but must remain astern of the followed vessel.

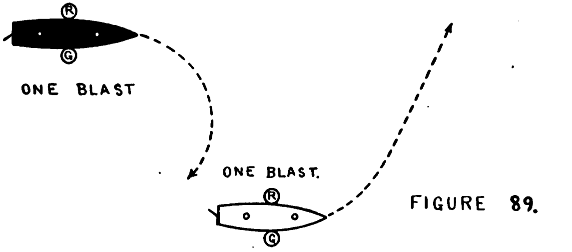
Fig. 88 may be instructive in that it shows how the white steamer should hold its course while the black ones over which she has better, or equal, rights must keep out of her way.

An interesting case occurs when two steamers are moving in the same direction on parellel courses, the faster one having the other on her own port side, and no previous signals having been exchanged. Under these conditions the faster steamer may, if circumstances demand it, alter her course and cross the bows of the slower vessel, as is shown in Fig. 89, although by so doing she must assume the responsibility for any accident due to her change in course. The faster steamer should give one blast and simultaneously give left rudder, alter her course to port and hold this new direction, while the other steamer should answer by one blast, give right rudder and pass astern of the black steamer.

It may be observed that when the steamer having the other on its own port side gave one blast she turned to port instead of to starboard as is usually done upon giving one blast, but the signal referred to the fact that having once altered her course she intended to *hold* that course and speed until danger of collision had passed.

The vessel whose bow was crossed would be obliged to reply by one blast, for cross signals such as answering one blast by two, or *vice versa,* are never permitted. Her





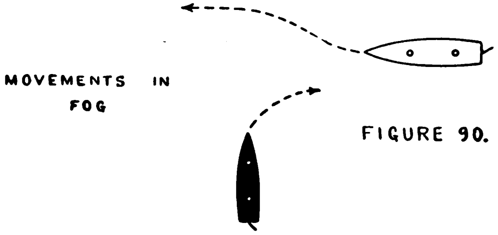


FIG. 88.—Showing that the white steamer should hold its course, while the black ones must keep out of her way.

FIG. 89.—Showing a steamer (white) having right of way changing her course to port to cross the bow of a slower steamer on a parallel course.

FIG. 90.—Showing suggested manœuvring of two steamers approaching in a fog, neither one of which can see the other.

only recourse, if she thought the action of the steamer attempting to cross her bow involved risk of collision, would have been to sound warning whistles of at least four short, sharp blasts and if necessary reverse her engines, at the same time giving three ordinary blasts. The steamer suggesting the manœuvre must then desist

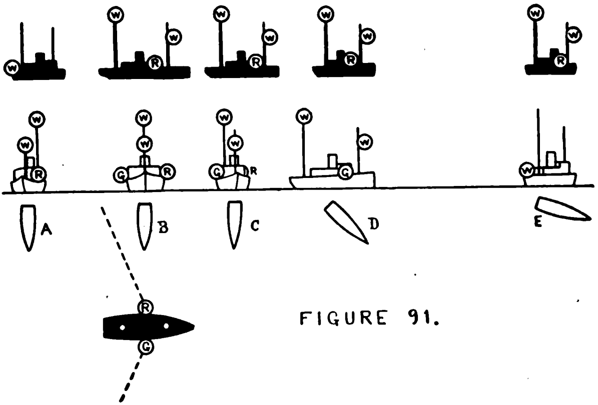


FIG. 91.—Showing how the range lights of a steamer tell us the direction in which she is heading. Above each white steamer there is a figure showing how the black steamer appears as seen from the white steamer.

from her attempt, or stop until an understanding has been reached by further exchange of signals.

Always observe the white range lights of an approaching steamer for these give you an immediate clue to the direction of her course; the forward range light being lower than the one on the after mast. Moreover, as the side lights and range lights, of an ocean steamer, show through only 20 points ahead they suddenly disappear just as the stern light comes into view, as shown in E, Fig. 91, wherein the black steamer has right of way over all the white steamers except E, in respect to which the black one is a following vessel.

A sailing vessel has right of way over all boats propelled by machinery except when she is a following vessel. A sailing vessel on the starboard tack has right of way over a sailing vessel on the port tack. A boat close hauled has right of way over one running relatively free. When both are running free with the wind on the same side, the vessel to windward must give way to the one to leeward. If both are running free with the wind on opposite side, the vessel which has the wind on the port side must keep out of the way of the other, and in general the vessel which has the wind aft must keep out of the way of the other vessel.

FOG SIGNALS

Next to those relating to rules of the road, fog signals are most important in navigation.

A steamer under way in a fog must go at slow speed, and give a prolonged blast of from four to six seconds' duration at regular intervals of not more than one minute, if in inland waters, nor more than two minutes if on the high seas.

A steamer under way but stopped sounds two prolonged blasts in rapid succession with an interval of not more than two minutes between them.

A vessel towing, or being towed, out of control but making headway, or laying a cable must give at intervals of not more than one minute a prolonged blast followed by two short ones. A vessel being towed may give this signal and she shall give no other.

A fishing vessel engaged in trawling or dredging must give at intervals of not more than one minute a prolonged blast followed at once by ringing a bell. Any vessel at anchor, aground, or with dredges or lines fouled on the bottom must ring the bell rapidly at intervals of not more than one minute.

Sailing vessels may use fog horns, and if on the starboard tack, must sound one blast each minute, if on the port tack two blasts in succession, and if with wind abaft, three blasts in succession each minute.

Never give rule of the road signals in a fog until you can see the vessel to whom you desire to signal. If you suddenly hear the fog whistle of an approaching but invisible steamer ahead and on your own starboard bow, it is best to turn at once in the direction of the sound (Fig. 90), at the same time stopping or backing your engines, thus minimizing the risk of collision. When your vessel has stopped, you may give two prolonged blasts in rapid succession at intervals of not more than two minutes, and this will inform the other steamer of the fact that you have no way on. As soon as you resume your headway give a prolonged blast.

The condition is shown in Fig. 90, wherein your vessel is represented in black. The other vessel which has right of way had best sheer off to starboard and perhaps increase, or at least maintain, her speed. However, the best action for each special case in a fog must be decided at once in a cool, carefully considered manner. Form your plan as quickly as possible and act upon it consistently, and above all do not confuse the other vessel by changing your mind. Know what you intend to do before you act.

ENGINE-ROOM SIGNALS

The modern "telegraph dial," when operated from the bridge rings a gong and records the order upon a corresponding dial in the engine room, which then responds by an answering signal which in turn appears on the dial on the bridge. We may thus signal "stand by," "stop," "ahead slow," "ahead ½ speed," "full speed ahead," "back slow," "back ½ speed," "back full speed," etc.! but apparatus is apt to be thrown out of order, especially in time of war, so one must be familiar with the old-fashioned gong and jingle-bell signals which for ocean and coasting steamers are as follows:

A jingle-bell may be given as a preparatory signal to stand by to receive signals.

Condition of engine	Signal	Order
Stopped	1 gong	Ahead slow
Stopped	2 gongs	Astern slow
Ahead slow	1 jingle	Ahead full spead
Ahead slow	1 gong	Stop
Full speed ahead	1 gong	Slow down
Full speed ahead	2 gongs	Stop
Full speed ahead	4 gongs	Astern full speed *
Astern slow	1 gong	Stop
Astern slow	1 jingle	Astern full speed
Astern full speed	1 gong	Stop

One gong always stops a backing engine.

INTERNATIONAL CODE FLAGS AND SIGNALS

Every mariner should be familiar with the international code flags, by which, with the aid of the code book published by the Unitel States Government, all manner of signals may be exchanged. In order to avoid confusion in verbal orders, these flags are referred to in our Navy as Able, Boy, Cast, etc., instead of A, B, C, etc. These flags and their naval names are shown in Fig. 92.

In this brief treatise, it will be impossible to do justice to the all important subject of signalling, which would require a volume in itself, and one should consult the "Deck and Boat Book of the United States Navy."

The semaphore system by machine and hand flags is also an essential in the training of every naval officer,

* Some authorities state that this emergency signal should order half speed astern, and that four gongs and a jingle should be the order for full speed astern. It is well to have an understanding with your engineer on this matter.

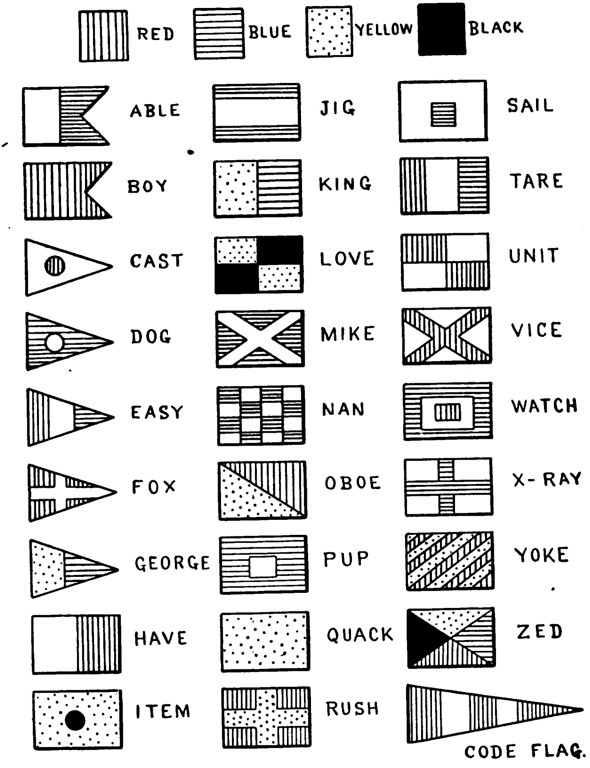


FIGURE 92

FIG. 92.—International code flags and code pennant.

and can be learned only by practice in both transmitting and receiving signals. The hand-flag system is illustrated in Figure 93, taken from the Signal Book of the United States Army.

A knowledge of the Morse code is becoming more and more essential as it enters into systems of signalling

THE TWO-ARM SEMAPHORE CODE WITH HAND FLAGS.

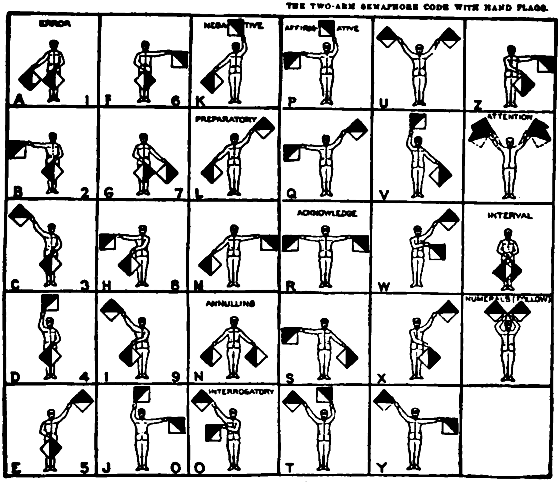


FIGURE 93.

FIG. 93.—Semaphore system of signals by machine and by hand flags from the "Signal Book" of the U. S. Army.

not only by wireless but by blinker lights, the wig-wag flag system, and sound signals.

The international Morse code for wireless and wig-wag is illustrated in Fig. 94, the dots being shown by short, and the dashes by long lines.

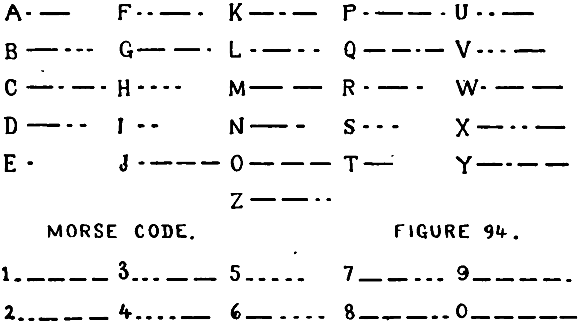


FIG. 94.—International Morse code alphabet.

DISTRESS SIGNALS

In the day time, signals of distress may be made by firing a gun or other explosive at intervals of about one

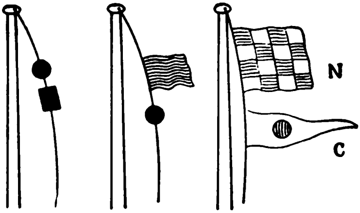


FIGURE 95.

FIG. 95.—Distress signals.

minute; by the continuous sounding of the whistle or fog horn, by the national ensign hoisted upside down, or by the international code flags NC. We may also signal distress by hoisting a square shape or flag having above or below it a ball or something resembling a ball.

By night, distress signals are made by flames, as from a tar barrel or kerosene can burned on deck, or by a gun fired at intervals of about one minute, or by rockets of any color, or the continuous sounding of the fog horn.

PILOT SIGNALS

A pilot may be signalled by the Union Jack hoisted at the foretop, or by a cone apex upward with two shapes resembling balls above it; also by the international code

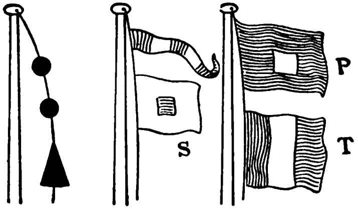


FIGURE 96.

FIG. 96.—Signals used to call a pilot.

flags PT, or by S with or without the code penant above it. At night, one may burn a blue pyrotechnic light every 15 minutes, or flash a white light at frequent intervals from the bridge.

The ensign set about half way up on the shrouds, or main rigging, is properly the signal for a tow boat, although it usually brings a pilot also.

STORM SIGNALS

Finally, is it important to know the meaning of the storm and high-wind signals hoisted in ports over the offices of the U. S. Weather Bureau. These signals are made by red or white pennants, separately or combined with a square red flag having a black center, as is shown in Fig. 97.

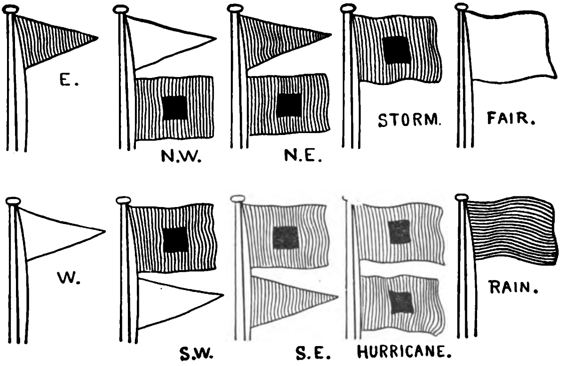


FIG. 97.—Storm and wind signals of the United States Weather Bureau.

The red pennant by day and a red light by night, indicate easterly winds, while the white pennant, or, at night, a white over a red light indicate westerly winds. The storm flag is a red square with black square center, and the hurricane signal is made by hoisting two of these flags one over the other. In reading the combination flag signals, one may remember that a pennant above the square flag refers to northerly winds, while the square flag above the pennant refers to southerly winds; then recalling that the red pennant is for easterly and the white for westerly winds, we have the clue to the whole matter.

A square white flag predicts fair, and a blue rainy weather, while temperature is shown by a black pennant placed above the weather flag for rising, and below for lowering temperature, and a white flag with a central black square tells that a cold wave is coming. The predictions are for the 24 hours following 8 A.M. of the day upon which the flags are displayed.

INDEX