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ELEMENTS OF NAVIGATION

[See p. 59

NAVIGATOR TAKING A SIGHT

Elements of Navigation

A complete Exposition of the Newest Methods as used in the Navy and Merchant Marine

BY

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NEW YORK NAVAL MILITIA

AN ENTIRELY NEW EDITION
REWRITTEN THROUGHOUT AND
BROUGHT UP TO DATE

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TO

COMMODORE ROBERT P. FORSHEW

COMMANDING THE NAVAL MILITIA

NEW YORK

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CONTENTS

PREFACE

This is literally a new edition, inasmuch as the book has been rewritten. The science of navigation has been materially modified in recent years and the practice of the navy has introduced changes looking toward celerity in arriving at results. Formulæ which a few years ago were regarded as of prime importance have been relegated to secondary places, and some entirely abandoned, while new ones have assumed the leading positions.

The author has therefore remodeled this entire work. All that was of permanent worth in the edition preceding this has been retained, but some of it has been amplified with the purpose of making the explanations still clearer.

Special stress has been laid on the necessity of learning all the systems of marking compass bearings and courses and making the corrections for variation and deviation. Azimuths of the sun are introduced at this point, but other methods of finding deviation are postponed till later in the book.

PREFACE

The treatment of dead reckoning has been expanded and the working of the traverse illustrated in the full navy form as now used. The recommencement of dead reckoning from observations in the course of the day's work is explained.

The sections dealing with latitude sights have been rewritten and arranged in a different order and the use of the prepared constant is thoroughly explained and illustrated.

While ex-meridians are retained the "Phi Prime and Phi Second" sight is omitted. It has no longer any practical value since the St. Hilaire method accomplishes all that it used to. The treatment of all sidereal work in this edition is newly written, and the former explanation of sidereal time and right ascension made clearer. Relations of hour angles and right ascensions are illustrated fully by diagrams.

The use of the haversine in time sights supersedes that of the sine of apparent time.

The Sumner method is, of course, accorded its proper importance and new diagrams introduced, but the section dealing with the St. Hilaire method has been greatly enlarged. In it the author has introduced a formula of his own for applying the St. Hilaire principle to meridian sights. This formula has been submitted to the Hydrographic Office and pronounced correct. Graphic diagrams are presented.

The section on the navigator's routine at sea has been rewritten entirely with a view to bringing it more into conformity with the present naval practice.

A chapter on the compensation of the compass has been added, with detailed instructions as to how to find and record deviations, how to adjust all corrections, and how to make and use the Napier curve.

Finally, everything in the book has been arranged so as to instruct the student in the navy way of doing things on the ships now at sea. The work is in complete harmony with Bowditch, but its explanations are designed to meet the needs of students who are not astronomers nor mathematicians.

The author is gratified at the reception accorded to the revised editions published in 1917. But since the United States entered the war he has been engaged in instructing naval militia and naval reserve officers and has profited by the experience. It is his confident belief that the present edition will be found a marked improvement on its predecessors.

The author's thanks are due to Rear-Admiral Seton Schroeder, Hydrographer, Navy Department, for his courteous consideration of the work mentioned under St. Hilaire Method; and he also owes a debt of gratitude to his capable colleague, Mr. Frank Seymour Hastings, for examination and cor-

rection of all illustrative problems which have been worked up for the present year. Thanks are also due to Mr. John Bliss, of John Bliss & Co., the well-known compass adjuster, for assistance in preparing the matter on compass compensation.

ELEMENTS OF NAVIGATION

ELEMENTS OF NAVIGATION

THE COMPASS

NAVIGATION is the art of finding the geographical location of a vessel at sea, the most direct course to be steered in pursuit of the voyage, and the distance to be made.

There are two branches of the art—dead-reckoning and observation.

Navigation by dead-reckoning consists in actually measuring the courses and distances sailed by the ship, and from them computing the distance and direction from the port left and to the port sought.

Navigation by observation consists in computing the position of the ship by the application of astronomical and mathematical laws.

The problems of dead-reckoning are solved by plane trigonometry; those of observation by spherical trigonometry. But as the trigonometrical data are all provided in the tables printed in epitomes of navigation, the mariner is not required to be acquainted with any higher methematics than simple arithmetic.

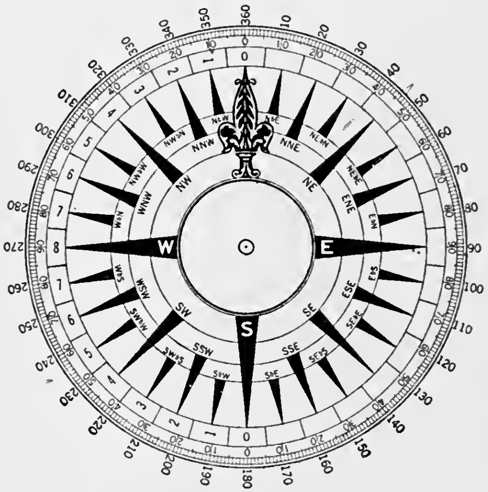
The instruments used in dead-reckoning are the compass, log, and lead-line. The compass shows the direction in which the ship is traveling; the log measures the speed or the distance. The lead is used when on soundings to measure the depth of water and ascertain the character of the bottom. These data, referred to in the chart, throw valuable light on the question of the ship's position. Approaching a coast in thick weather, or on a dark, cloudy night, the lead is the navigator's main reliance.

In addition to these instruments, the navigator requires for all his work accurate charts of the waters which he is traversing and their coasts. Charts issued by governments are more trustworthy than those published by private firms, which have not the resources of nations.

The mariner's compass is the first instrument which the navigator must know. It is presumed that any person who reads this book has seen a compass; therefore it is not described. The card is the part which concerns the learner at this point. Its circumference is divided into 32 equal parts, called points. Each point has a name; all these names the student must learn.

Any intelligent person can easily discover the system on which the points are named.

North, south, east, and west are called the cardinal points; northeast, southeast, southwest, and northwest are the intercardinal points. Each cardinal point is 8 points away



COMPASS-CARD, SHOWING POINTS AND DEGREES

from the nearest cardinal, and 4 points away from the nearest intercardinal. The student must learn to repeat the names in order from north to east and around to north again, thus:

North, north-by-east, north-northeast, northeast-by-north, northeast, northeast-by-east, east-northeast, east-by-north, east, east-by-south, east-southeast, southeast-by-east, southeast, southeast-by-south, south-southeast, south-by-east, south, south-by-west, south-southwest, southwest-by-south, southwest, southwest-by-west, west-southwest, west-by-south, west, west-by-north, west-northwest, northwest-by-west, northwest, northwest-by-north, north-northwest, north-by-west, north.

This is called "boxing the compass." In reckoning courses by their names we always count from the north and south line of the compass, which is called the meridian. Thus north-northeast, south-southeast, north-northwest, and south-southwest are 2-point courses. East and west are 8-point courses. Southeast-by-south is a 3-point course. The student should learn how many courses of each kind there are, bearing in mind that there is nothing greater than an 8-point course. After a careful study of the points the student should be able to answer with facility all such questions as these:

How many 1-point courses are there? 2-point? 3-point, etc.? Name them. How many points is it from E.S.E. to S.W.-by-S.? How many points from N.E.-by-E. to W.-by-S.? How many points from E.-by-

S. to E.N.E.? What points are 3 points away from W.-by-N.?

Until the student is master of the points of the compass and their relations he should go no further. When he has learned them, he must acquaint himself with the half and quarter points as set forth in the following tables. (See pages 6 and 7.)

The next step is to learn the angle which each course makes with the meridian. Meridians are imaginary lines running from the north to the south pole and used for determining longitude. The meridian of the compass is its north-and-south line, which for the moment may be assumed to coincide with a longitude meridian. A ship sailing northeast makes a course at an angle of 45° from the meridian, and the compass shows us this.

The circumferences of all circles, no matter what their size, are divided into 360 equal parts called degrees. All angles are measured by these. These facts are of hourly use in navigation.

For example, in the diagram (see page 8) the angles at *a* do not increase in size because their boundary lines are prolonged. They will measure 45° on any circle, even the earth's circumference. A degree, therefore, is $\frac{1}{360}$ of *any* circle's circumference.

If you divide the 360° of the compass-card by its 32 points, you will learn that 1 point equals 11° 15′. By adding 11° 15′ for each

TABLE SHOWING THE NAMES OF POINTS AND QUARTER-POINTS, AND THE ANGLE MADE BY

North		Points	
N.¼E.	N.¼W.	¼	2° 48′ 45″
N.½E.	N.½W.	½	5° 37′ 30″
N.¾E.	N.¾W.	¾	8° 26′ 15″
N.-by-E.	N.-by-W.	1	11° 15′ —
N.-by-E.¼E.	N.-by-W.¼W.	1¼	14° 3′ 45″
N.-by-E.½E.	N.-by-W.½W.	1½	16° 52′ 30″
N.-by-E.¾E.	N.-by-W.¾W.	1¾	19° 41′ 15″
N.N.E.	N.N.W.	2	22° 30′ —
N.N.E.¼E.	N.N.W.¼W.	2¼	25° 18′ 45″
N.N.E.½E.	N.N.W.½W.	2½	28° 7′ 30″
N.N.E.¾E.	N.N.W.¾W.	2¾	30° 56′ 15″
N.E.-by-N.	N.W.-by-N.	3	33° 45′ —
N.E.¾N.	N.W.¾N.	3¼	36° 33′ 45″
N.E.½N.	N.W.½N.	3½	39° 22′ 30″
N.E.¼N.	N.W.¼N.	3¾	42° 11′ 15″
N.E.	N.W.	4	45° — —
N.E.¼E.	N.W.¼W.	4¼	47° 48′ 45″
N.E.½E.	N.W.½W.	4½	50° 37′ 30″
N.E.¾E.	N.W.¾W.	4¾	53° 26′ 15″
N.E.-by-E.	N.W.-by-W.	5	56° 15′ —
N.E.-by-E.¼E.	N.W.-by-W.¼W.	5¼	59° 3′ 45″
N.E.-by-E.½E.	N.W.-by-W.½W.	5½	61° 52′ 30″
N.E.-by-E.¾E.	N.W.-by-W.¾W.	5¾	64° 41′ 15″
E.N.E.	W.N.W.	6	67° 30′ —
E.N.E.¼E.	W.N.W.¼W.	6¼	70° 18′ 45″
E.N.E.½E.	W.N.W.½W.	6½	73° 7′ 30″
E.N.E.¾E.	W.N.W.¾W.	6¾	75° 56′ 15″
E.-by-N.	W.-by-N.	7	78° 45′ —
E.¾N.	W.¾N.	7¼	81° 33′ 45″
E.½N.	W.½N.	7½	84° 22′ 30″
E.¼N.	W.¼N.	7¾	87° 11′ 15″
East.	West.	8	90° — —

additional point you will learn that 2 points equal 22° 30′; 3 points, 33° 45′; 4 points, 45°; 5 points, 56° 15′; 6 points, 67° 30′; 7 points, 78° 45′; and 8 points, 90°. Sailing-vessels cannot be steered closer than a quarter of a

NUMBER OF POINTS AND FRACTIONS OF POINTS IN EACH COURSE, EACH WITH THE MERIDIAN.

South		Points	
S.¼E.	S.¼W.	¼	2° 48′ 45″
S.½E.	S.½W.	½	5° 37′ 30″
S.¾E.	S.¾W.	¾	8° 26′ 15″
S.-by-E.	S.-by-W.	1	11° 15′ —
S.-by-E.¼E.	S.-by-W.¼W.	1¼	14° 3′ 45″
S.-by-E.½E.	S.-by-W.½W.	1½	16° 52′ 30″
S.-by-E.¾E.	S.-by-W.¾W.	1¾	19° 41′ 15″
S.S.E.	S.S.W.	2	22° 30′ —
S.S.E.¼E.	S.S.W.¼W.	2¼	25° 18′ 45″
S.S.E.½E.	S.S.W.½W.	2½	28° 7′ 30″
S.S.E.¾E.	S.S.W.¾W.	2¾	30° 56′ 15″
S.E.-by-S.	S.W.-by-S.	3	33° 45′ —
S.E.¾S.	S.W.¾S.	3¼	36° 33′ 45″
S.E.½S.	S.W.½S.	3½	39° 22′ 30″
S.E.¼S.	S.W.¼S.	3¾	42° 11′ 15″
S.E.	S.W.	4	45° — —
S.E.¼E.	S.W.¼W.	4¼	47° 48′ 45″
S.E.½E.	S.W.½W.	4½	50° 37′ 30″
S.E.¾E.	S.W.¾W.	4¾	53° 26′ 15″
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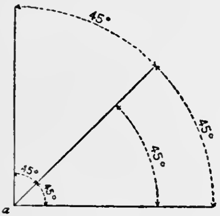
E.½S.	W.½S.	7½	84° 22′ 30″
E.¼S.	W.¼S.	7¾	87° 11′ 15″
East.	West.	8	90° — —

point, and for their navigation a quarter may be called 3°. Steamers can be steered to degrees, and their courses are so set. They may be expressed as so many degrees east or west from the meridian, thus: N. 47° E., or S. 36° W.



MEASUREMENT OF ANGLES

The latest method, however, and that always used in the navy, is to count the degrees all the way around from N. by way of E. and S. back to N., and set courses accordingly. The count runs from 1° to 360° and geographical direction is omitted, so that courses are expressed simply as being of so many degrees, as, for example, 46°, 137°, 220°.

Every navigator should master thoroughly the relations of courses reckoned in one way to the same reckoned in another. For example, he should know that every course up to 89° would be found in the northeast quadrant of the compass; those between 90° (E.) and 180° (S.) in the southeast; those between 180° (S.) and 270° (W.) in the southwest, and those between 270° and 360° in the northwest.

How express S. 27° W. in 360° system? S. = 180°. This + 27° = 207°.

How express S. 27° E.? 180° − 27° = 153°.

How express N. 27° W.? 360° − 27° = 333°.

How express W.-by-N.? 270° + 11° = 281°.

How express intercardinal points? N. E. = 45°; S. E. = 135°; S. W. = 225°; N. W. = 315°.

VARIATION

The north point of the compass indicates true or geographical north at only a few places on the globe. At all other places it points a little to one side or the other of north. This error is called variation of the compass.

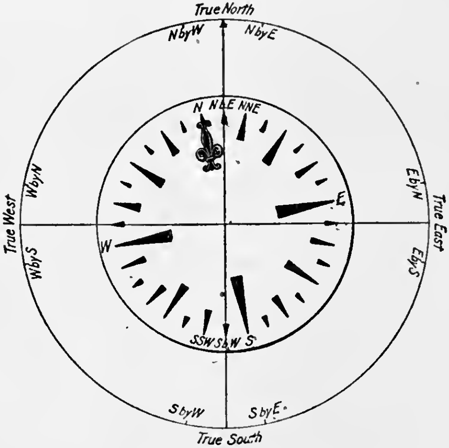
It is caused by the fact that the magnetic north and south poles of the earth do not coincide with the true or geographical poles. The former is several hundred miles south of the geographical pole, and the latter several hundred miles north. The needle is perfectly true; it points right at the magnetic north pole. But that pole is not the north end of the earth's axis.

In navigating a vessel it is necessary to make allowance for this variation. The amount of allowance and its direction are indicated on the charts. On large charts, such as that of the North Atlantic, will be found irregular lines marked 10° W., 15° W., etc. This means that along this line the variation of the compass from true north is 10° W., 15° W. There are certain lines which have no variation, and here no allowance is to be made. On small charts, such as that of New York Bay, the variation is shown by the compass-card printed on the chart. The north point of it will be found slewed a little to the eastward or westward of a meridian line, and near it will be seen an inscription, such as "Variation 11° W. in 1892." Now let us see how this variation affects the compass aboard ship, and how we are to allow for it, so that we shall know exactly which way we are going.

Let the outer circle represent the sea horizon, the inner circle the compass-card. The variation is one point westerly. Hence the north point of the compass points to the north-by-west point of the horizon, and the south point of the compass to the south-by-east point of the horizon. In other words, standing at the center and looking toward the circumference, you find that every point on the compass is one point to the left of the proper place. If your compass says you are sailing north, you are really sailing N.-by-W. If its says south, you are going S.-by-E. If it says east, you are going E.-by-N. Hence we get these rules:

To correct a compass course.—When the variation is westerly, the true course will be as many points to the *left* of the compass course as there are points of variation. When the variation is easterly, the true course will be as many points to the *right* of the compass course.

Conversely, having ascertained the true course between two places, you must construct the required compass course by applying the variation in a direction the reverse



VARIATION OF COMPASS

of that used in converting a compass to a true course.

To convert true course to compass course.—Variation westerly, compass course to *right* of true course. Variation easterly, compass course to *left* of true course.

When working courses reckoned from 1° to 360°, westerly variation is called −, and easterly +. To convert compass to true course, *subtract* amount of W. var.; *add* amount of E. var. To convert true to compass course, reverse the process, *adding* W. var., and *subtracting* E.

A course or bearing affected only by var. (and not by deviation) is called magnetic.

DEVIATION

In addition to the force of terrestrial magnetism, which affects all compasses alike, no matter how situated, we have to contend with *deviation,* which is error caused by the influence of neighboring iron or steel. In ships built of either metal the influence is great and no compass aboard such a ship is ever quite correct, except possibly on one or two courses. When the ship changes her course, the hull assumes a new relation to the direction of the needles of the compass, and hence the deviation changes.

Therefore it becomes necessary to know the error on each course. Compasses are compensated by the use of magnets, which reduce error to the minimum, but some always remains. A fuller explanation of the cause, the nature, and the treatment of deviation will be given in a chapter on compass compensation. At present it is only necessary to note that when the compass has been compensated, a table of the residual errors is made for the information of the navigator. Since, however, the deviations are liable to change in voyages involving much alteration of latitude, the tables cannot be too implicitly trusted.

Deviation is ascertained on every fifteenth degree of the circumference of the compass, and the table of residual errors would begin thus:

Ship's Head by Standard Compass		Deviation
North	0°	− 14° 27′
	15°	− 12° 10′
	30°	− 9° 38′
N. E.	45°	− 7° 12′
	60°	− 6° 02′
	75°	− 4° 55′
E.	90°	− 3° 10′

Deviations are named easterly (+) or westerly (−), just as variation is, and the correction is applied by the same rules.

AZIMUTHS OF THE SUN

Deviations are found at sea by what are called azimuths of celestial bodies. The process consists in taking a compass bearing of the object and comparing it with the true bearing. The true bearing at any time may be computed from the altitude and declination of the body, and the latitude of the observer. To save labor we have sets of azimuth tables giving the true bearing of the sun for every ten minutes of the day.

The most familiar instrument for taking the compass bearing is the azimuth mirror, a circular contrivance which fits over the compass and has sight vanes for observing the body and a mirror which throws a reflected beam of light on the compass-card, thus showing the bearing.

Having taken the compass bearing and ascertained the local time of the observation, enter the azimuth tables (Hydrographic Office, Book, No. 71), with the declination above and the time at the side. You must seek the page marked at the top with your latitude, and note that the book is divided into two parts, lat. and dec. of same name, and lat. and dec. of different names. Be careful to select the proper page and then pick out the true bearing to the nearest degree. Azimuths are read from N. toward E. or W. when you are in N. lat., and S. to E. or W. in S. lat.; thus, N. 120° W., S .60° E. After picking them out in this form, you must convert the reading to that of a compass bearing. N. 120° W. = S. 60° W., or 240°.

The difference between the compass and the true bearings is the total error of the compass. The difference between the total error and the variation as given by the chart is the deviation.

How to determine the correct local time, and how to use other celestial bodies, will be explained further on. The best way of computing the deviation is to find the diff. between comp. and true bearings, and then between error and variation.

Compass bearing..	N. 75° E.	Compass bearing...	S. 15° W.
True bearing......	N. 55° E.	True bearing......	S. 20° W.
Error..........	20° W.	Error...........	5° E.
Var............	10° W.	Var............	10° W.
Dev...........	10° W.	Dev.............	15° E.

When the courses are set in degrees in the 360° system, the formula for correcting a compass course is:

$$T.\ C. = C.\ C. + Var. + Dev.$$

T. C. means true course; C. C., compass course. Easterly var. or dev. is plus; westerly is minus. If both quantities have the same sign, add the two and prefix the sign. If the quantities have different signs, subtract the less from the greater and prefix the sign of the greater. Apply resultant quantities to C. C. in each case and obtain T. C.

Examples:

1.—Compass course, 195°. Variation, 20° W. Deviation, 5° W. Required, true course. Westerly error is a minus quantity, hence:

Var.	−20°	C. C.	195°
Dev.	− 5°	Error	− 25°
Error	−25°	T. C.	170°

2.—C. C., 195°. Var., 20° E. Dev., 5° E. Required, T. C. Easterly error is always a plus quantity. Hence:

Var.	+20°	C. C.	195°
Dev.	+ 5°	Error	+25°
Error	+25°	T. C.	220°

3.—C. C., 195°. Var., 20° E. Dev., 5° W. Required T. C.

Var.	+20°	C. C.	195°
Dev.	− 5°	Error	+15°
Error	+15°	T. C.	210°

4.—C. C., 195°. Var., 20° W. Dev., 5° E. Required, T. C.

Var.	−20°	C. C.	195°
Dev.	+ 5°	Error	− 15°
Error	−15°	T. C.	180°

Given the T. C., Var., and Dev. to find the C. C. to be steered, the navigator reverses the former process by changing the signs prefixed to easterly and westerly errors. Easterly becomes minus and westerly plus.

Examples:

1.—T. C. 170°. Var., 20° W. Dev., 5° W. Required, C. C.

Var.	+20°	T. C.	170°
Dev.	+ 5°	Cor.	+ 25°
Cor.	+25°	C. C.	195°

2.—T. C., 180°. Var., 20° W. Dev., 5° E. Required, C. C.

Var.	+20°		T. C.	180°
Dev.	− 5°		Cor.	+ 15°
Cor.	+15°		C. C.	195°

The student will note that these are reverse workings of the first and fourth examples of the correction of a C. C. to find T. C. and they bring us back to our former C. C. A little practice will convince the student that the new method is easier than the old.

Keep all loose iron and steel as far as possible from your compasses. Bear in mind that magnetic influence will not be stopped by placing anything between the compass and the iron or steel. It will pass through a stone wall.

Make it an invariable rule to ascertain the deviation of the compass on every course steered and to correct the course accordingly.

Bear in mind when ascertaining your deviation that it is good only for that one course. If your ship is heading E.S.E. and you find the deviation to be 10° E., it will be something else the moment you alter the course to E.-by-S., or even E.S.E.½E.

Bear in mind in taking bearings to apply the deviation *according to the direction of the ship's head.*

For instance, you are lying at anchor. Your compasses have just been adjusted.

The ship's head points N.W.-by-N. The table of errors says that on that course the deviation is one point easterly. Directly on your starboard beam is a light house. You wish to get its bearing. The compass says it bears N.E.-by-E. But you have one point easterly deviation. Hence the correct compass bearing is E.N.E.

Large vessels carry more than one compass. One of these is situated above the deck and as far away from local influences as possible. It is called the standard compass, and the ship is navigated by it.

To set a course by a standard compass.—Stand by the standard yourself and station a man at the steering compass. Order the helm to port or starboard till the ship is precisely on her course by the standard. At that instant blow a whistle (or give any other preconcerted signal), and the man at the steering compass notes the direction of the ship's head according to it. The course which he gets is the one to be given to the helmsman.

USE OF THE PELORUS

In ascertaining deviations and in all other operations requiring the taking of bearings the pelorus will be found useful. The instrument is a type of dumb compass, which may be set up in any convenient place. It has an outer ring of brass with the degrees marked thereon, and within this is a dumb-compass card of ground glass. Outside of all revolves a pair of sight vanes through which bearings are taken.

If now the fore-and-aft line of the dumb card is made to coincide with the course of the ship, bearings taken by pelorus will be the same as those taken by the compass. If the deviation is known and is eliminated, the pelorus may be set accordingly, and all bearings will be magnetic. If the variation and deviation are both eliminated, bearings by pelorus will be true.

LEEWAY

Leeway is, of course, not an error of the compass; but as it has to be considered in the correction of compass courses in dead-reckoning, it is convenient to introduce the subject here. A sailing-vessel on a wind, or even with the wind abeam, will slide off to leeward more or less. A strong wind will affect even a steamer. Consequently her actual course will not be that indicated by compass, even when corrected for variation and deviation.

To find the leeway.—Experienced sailors can estimate the leeway by the angle between the vessel's wake and her keel. A good plan, however, is to heave the log, then bring the line to the center of the compass, and its angle with the vessel's course will show the amount of leeway.

To correct for leeway.—Leeway on the starboard tack is the same as westerly variation. Leeway on the port tack is the same as easterly variation. The corrections are made in the same way. A glance at the diagram

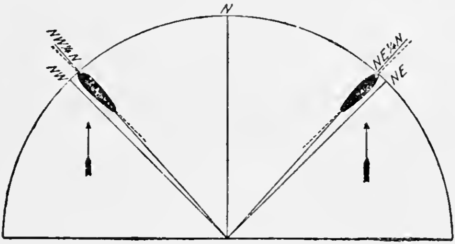


DIAGRAM OF LEEWAY

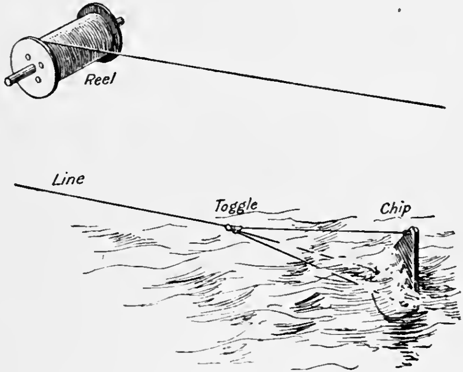
will make this clear. The vessel heading N.E. on the starboard tack and making a quarter-point of leeway is actually going N.E.¼N. The vessel on the port tack heading N.W. and making a quarter-point of leeway is really going N.W.¼N.

A good point to remember is this: leeway on the port tack and westerly variation or deviation are opposed to one another, and the same is true of leeway on the starboard tack and easterly error. For example, you have a quarter-point westerly variation, no deviation, and a quarter-point leeway on the port tack; the leeway and variation counterbalance one another, and the compass course is the true course. The form given in the following examples for practice is used in computing dead-reckoning:

Compass Course	Variation	Deviation	Leeway	True Course
S.W.-by-W.	½pt.W.	¼pt.W.	¼pt.Port	S.W.½W.
E.-by-S.	16° W.	10° E.	¼pt.Star.	E.¼S.
N.N.E.½E.	1 pt. E.	2 pts. W.	¼pt.Star.	N.¾E.
S. 42° E.	20° W.	25° E.	6° Port	S. 31° E.
S. 33° W.	5° E.	3° W.	3° Star.	S. 32° W.
227°	10° W.	4° W.	4° Star.	209°

THE LOG

There are two kinds of logs, the chip log and the patent or taffrail log. The principal parts of the chip log are the chip, the reel, the line, and the toggle. A second-glass is used for measuring the time. The chip is a triangular piece of wood, rounded on its lower edge and ballasted with lead to make it ride point up. The toggle is a little wooden case into which a peg, joining the ends of the two lower lines of the bridle, is set in such a way that a jerk on the line will free it, causing the log to lie flat so that it can be hauled in. The inboard end of the line is wound around the reel. The first 10 or 15 fathoms of line from the log-chip are called "stray line," and the end of this is distinguished by a mark of red bunting 6 inches long. Its purpose is to let the chip get clear of the swirl under a vessel's counter before reckoning begins.



CHIP LOG AND REEL

The knots, as they are called, are distinguished by running pieces of fish-line through the strands to the number of one, two, three, etc. A piece of white bunting, two inches long, marks every two-tenths of a knot. This is because the run of a ship is recorded in knots and tenths.

A new log-line should be soaked in water a few days before marking, and always before leaving port you should soak your line and then see that the marks are all at the proper distances.

The log-glass, in appearance like an hour-glass, measures 28 seconds. For high rates of speed, a 14-second glass is used, and then the number of knots shown by the line must be doubled. In damp weather a watch is better than a sand-glass.

The principle of the chip log is that the length of a knot bears the same ratio to the nautical mile (6,080 feet) as the time of the glass does to the hour. Hence we get this proportion:

3600*: 6080 : : 28 sec. : x
x = 47 feet 9 inches.

The speed of the ship is recorded in the log-book in knots and tenths of a knot.

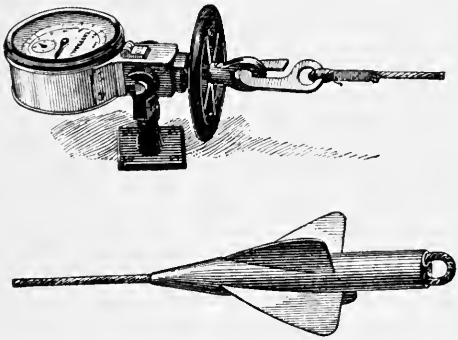
How to heave the chip log.—Have an assistant to hold the glass. See that all the sand is in the bottom. Heave the log-chip well out to leeward from the stern, and hold the reel so the line will run freely. As soon as the stray line is out call "Turn," and the assistant must turn the glass quickly and start the sand running. The instant the sand has passed down the assistant must

* Number of seconds in an hour.

call "Stop," and you check the line. Note the number of knots and tenths and haul in.

The chip log should be hove every hour. If the speed varies between hours it must be estimated, or the log hove again.

The patent or towing log consists of a dial, a line, and a rotator of screw-propel-



PATENT OR TOWING LOG

ler form. The action of the water on the rotator, which is at the end of the line and thrown overboard, causes the line to make a certain number of twists a minute. These twists are proportional to the speed of the vessel, and they move the machinery of the dial, which records miles and fractions of a mile.

In setting a taffrail log to work, you must note where the dial stands at the time when you throw over the rotator. The reading of the log is noted in the log-book once an hour, and whenever the course is changed. It should also be read when an observation is taken.

Both logs are liable to error. The rotator of the patent log slips sometimes, and that underrates the distance gone. Usually, however, it overrates. The chip log is likely to underrate with a following sea, which causes the chip to "come home," and to overrate a little with a head sea.

In shallow water, but out of sight of landmarks, a vessel drifting in a tideway may use a ground log. This is a common log-line with a hand lead attached, and it shows the actual speed of the ship over the *ground*.

THE LEAD-LINE

The lead is used to ascertain the depth of water, and, when necessary, the character of the bottom. There are two kinds of leads: the hand lead and deep-sea lead. The first weighs from 7 to 14 lbs., and has markings to 20 fathoms. The second weighs from 80 to 150 lbs., and is used in depths over 100 fathoms. The hand lead is marked thus:

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

Large hand leads and deep-sea leads are marked above 20 fathoms with an additional knot at every 10-fathom point (30, 40, 50, etc.), and a single knot at each intervening 5-fathom point (25, 35, 45, etc.).

Deep-sea leads are hollowed out on the lower end so that an "arming" of tallow can be put in. This will bring up a specimen of the bottom, which should be compared with the description found on the chart.

All first-class sea-going vessels should discard the deep-sea lead for Lord Kelvin's sounding-machine. This apparatus consists of a cylinder around which are wound about 300 fathoms of piano wire. To the end of this is attached a heavy lead. An index on the side of the instrument records the number of fathoms of wire paid out. Above the lead is a copper cylindrical case in which is placed a glass tube open only at the bottom and ground inside. The pressure of the sea forces water up into this tube, as it goes down, a distance proportionate to the depth, and the ground part, being wet, shows clear. When hoisted, the tube is laid upon a prepared scale, and the height to which the water has been forced inside shows the depth in fathoms on this scale.

CHARTS

A chart is a map of an ocean, bay, sound, or other navigable water, showing the conformation of the coasts, heights of mountains, the depth at low-water, direction and velocity of tidal currents, location, character, height and radius of visibility of all beacon lights, location of rocks, shoals, and buoys, and nature of the bottom wherever soundings can be obtained.

The top of the chart is generally north. If for any reason it is otherwise, north will be indicated by the north point of a compass-card printed somewhere on the chart.

On the majority of small charts, such as those of bays, harbors, and sounds, the compass on the chart includes the variation; that is, its north point is slewed east or west, just as that of a real compass (without deviation) would be in that place. In laying off courses by such a compass you do not have to allow for variation, because it is already allowed for. On large charts, such as that of the North Atlantic, the compass is printed true, and the variation is indicated by lines as described under the head of "Variation."

Parallels of latitude are shown by straight lines across the chart. The degrees and minutes are marked on the perpendicular border.

Meridians of longitude are shown by straight lines up and down the chart, and the degrees and minutes are recorded on the horizontal border.

The navigator should know the varieties of buoys. Channels on the United States coasts are indicated by red buoys with even numbers situated on the starboard side coming in from the sea, and black buoys with odd numbers on the port side.

Buoys with black-and-white perpendicular stripes are in mid-channel and must be passed close to.

Buoys with red-and-black horizontal stripes indicate obstructions with channels on both sides.

The abbreviations on charts are easily understood.

Soundings on plain white usually are in fathoms, especially in general charts, and those on shaded parts, in feet. In charts of small bodies, such as New York Bay, soundings are often *all* in feet.

To avoid error in this and other matters read carefully all text printed on the chart. It is there for your information.

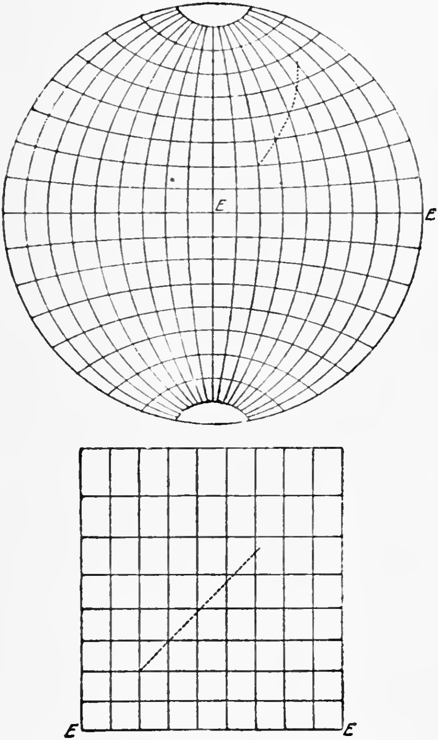
On general charts of coasts there are fathom curves, showing the lines along which run soundings of 10, 20, 30, etc., fathoms. These give valuable aid to the coastwise navigator, as well as to him approaching the coast from the ocean.

A light is indicated by a red and yellow spot. F. means fixed; Fl., flashing; Int., intermittent; Rev., revolving, etc.

An arrow indicates a current and its direction. The speed is always recorded.

Rocks just under water are shown by a cross surrounded by a dotted circle; rocks above water, by a dotted circle with dots inside it.

The charts used by mariners, except in great-circle sailing, are called Mercator's charts. Speaking roughly, this chart is constructed on the imaginary theory that the earth is cylindrical. Hence the meridians of longitude, which in a sphere (see page 30) converge at the poles, are opened out and become straight, parallel lines. This compels a stretching out in width of everything represented in high latitudes. To preserve the geographical relations the length is also stretched proportionately, so that although everything in high latitudes is on too large a scale as compared with places in lower latitudes, the courses and distances measured on a chart are correct. The advantage of a chart made in this way is that it enables the course of a ship to be represented by a straight line, whereas on a sphere it would be —and truthfully so—a curved one.



SPHERE COMPARED WITH MERCATOR'S CHART

In *very* high latitudes the inexactness of a Mercator's chart reveals itself fully. It is quite impracticable for polar navigation. For instance, how can you steer for the north pole on a chart whose meridians never come together at any pole, but are infinitely prolonged parallel lines? Owing also to this inexactness the bearings of distant objects are not always quite correct when laid down in straight lines on the chart. But, taking it all in all, the Mercator's chart is the one best adapted to the daily needs of the mariner.

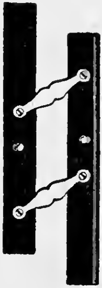
By means of the chart the navigator may at times sail along a coast in clear weather without having recourse to any other instruments of navigation than the compass and lead-line.

The instruments used in consulting the chart are the parallel rules, dividers, and course-protractor.

The parallel rules are made of ebony or gutta-percha. They are connected by cross-pieces of brass, working on pivots in such a way that the rules may be spread apart or pushed together, but will always remain parallel to each other.

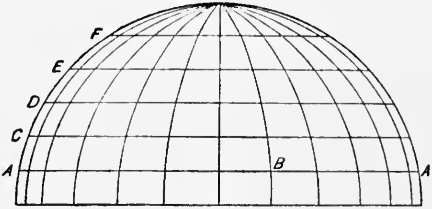
They are used to determine the direction of courses. For instance, you wish to find the course from Sandy Hook Lightship to Fire Island Light. Lay the parallel rules so that one edge cuts both places. Now slide first one rule and then the other, holding the unmoved one down firmly so as to retain the direction, till the edge cuts the center and circumference of the compass printed on the chart. The edge, if the direction has been preserved, will indicate the course.

The dividers are used to measure distance. On small charts take your distance from the scale of nautical miles; on large ones, from the latitude scale at the side of the chart. A minute of latitude is always a mile, because parallels of latitude are equidistant at all parts. A minute of longitude is a mile only at the equator, for the meridians are always coming nearer and nearer together, till at the pole they join and there is no longitude at all. Yet, as every parallel of latitude runs all the way around the earth, it is a circle and contains 360°. The distance from A to B will be the same number of degrees, minutes, and seconds whether measured on parallel A or parallel E, but it will not be the same number of miles. But the distances from A to C, from C to D, and from D to E must be the same on any meridian, because the lines A, C, D, and E are parallel. That is why distance is measured on the latitude scale.



PARALLEL RULES

Long courses are most conveniently shaped by the course-protractor. This consists of a long single rule upon which slides a movable disk marked as a compass-card. By laying



MINUTES VERSUS MILES

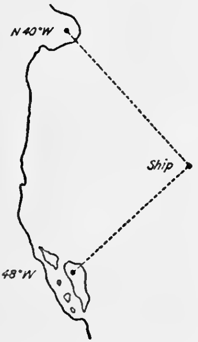
the rule down on the course and bringing the north point of its disk to coincide with a meridian, the angle of the course is at once seen. Variation can be allowed for in placing the disk's north point, if so desired.

CHART SAILING OR PILOTING

These titles cover various methods of locating the ship and ascertaining distances sailed.

Finding position by cross-bearings.—Select two charted objects whose bearings from the ship will be at right angles to each other, or nearly so. Take an accurate bearing of each. Correct bearings for the *deviation* known to exist *on the heading of the ship*, not on the direction of the bearings. With the parallel rules (applied to compass-card on chart) lay off the two lines of bearing with light pencil-marks on chart. Where they intersect will be the ship's position.

The ship's position may be accurately determined by measuring with a sextant the horizontal angles (see Distance and Danger Angles) separating three charted objects, and plotting the position with a three-armed protractor. This is a metal ring marked with degrees and having three arms, one fixed, two movable. The three arms can be set to the angles measured by sextant and then laid down on the charted objects. The center of the instrument will be at the ship's position.



MAP OF CROSS-BEARINGS

To find the distance between two places on the chart.—If the course is due north or south, measure the distance and refer it to the latitude scale on the side of the chart precisely opposite the course. The number of minutes in the distance as found in the scale will be the number of miles, because 1′ of lat. is one mile. If the course is east or west, follow same rule.

If the course runs diagonally, measure the distance on the latitude scale opposite the middle of the course. The best way is to take off the lat. scale with the dividers a convenient unit, such as two or five miles, and find how many times it is contained in the distance between the places.

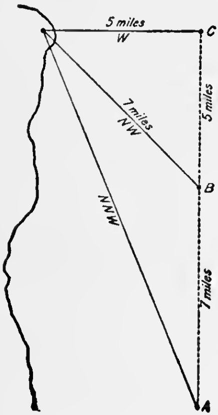
On charts of small areas, such as bays, use the scale of nautical miles found on the chart.

To find the latitude of a place on the chart.—Put one leg of the dividers in the place and the other in the nearest parallel of lat. Apply the dividers thus opened to the lat. scale at side of chart, one leg touching the same parallel as before. The other will be at the required lat. *To find a longitude*, do the same thing, but use a meridian and the long. scale at top or bottom of chart.

To mark the ship's place on the chart.—This is to be done at sea after finding the latitude and longitude. "With the dividers take from the graduated meridian the given latitude; mark this on the meridian nearest the given longitude; lay the edge of a pair of parallel rulers on a near parallel, and work one side of them to the exact latitude you have marked on the meridian; then with the dividers take the given longitude from the graduated parallel [at the top or bottom of the chart]; lay this down along the edge of the parallel rulers which already mark the latitude, and you have the ship's place" (Qualtrough).

To find the ship's position when sailing along the land.—Take a compass bearing of a light or other prominent object when it is 2, 3, or 4 points off the course. Take another bearing when it has doubled the first and is 4, 6, or 8 points off the course. The distance run by the ship between the two bearings will be her distance from the observed object at the second bearing.

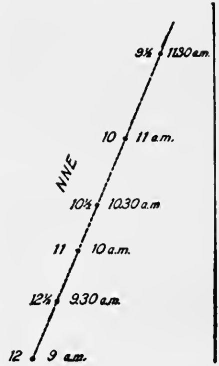
In the diagram the ship at A heading north finds the light bearing N.N.W., 2 points off her course. At B she finds it bears N.W., 4 points off. The log makes the distance from A to B 7 miles. The distance of the light from the ship at B will be the same. The commonest form of this problem is that used at positions B and C, with the object 4 points off the course and exactly abeam. This is known as the bow-and-beam bearing. The navigator will find cases in



COASTWISE BEARINGS

which the other form is convenient. This method should be practised continually, as it is the standard method in coastwise navigation. It is also valuable in establishing a final position with reference to the land when about to go to sea.

How to use compass, log, and lead in a fog.—Take a piece of tracing-paper and rule a meridian on it. Take casts of the lead at regular intervals, noting the time at which each cast is taken, and the distance logged between each two. The compass shows the course. Now rule a line on the tracing-paper in the direction of your course. Measure off on it by the scale of miles of your chart the distances run between casts. Opposite each cast note the time and the depth ascertained. It is a good thing to add also the character of the bottom. Now lay your tracing-paper down on the chart,



CHAIN OF SOUNDINGS

which can be seen through it, in the neighborhood of the position you believed yourself to be in when you made the first cast. If your chain of soundings agrees with those on the chart right under your course, all is right. If not, move the tracing-paper about, keeping the meridian line due north and south, till you find the place on the chart that does agree with you. That is where you are. You will not find two places where you can get that chain of soundings on the same course and at the same distances.

This is the *only* method by which a ship's position can be found with any certainty on soundings in thick weather. There is no excuse whatever for the man who runs his vessel ashore, if he has not tried this.

DEAD-RECKONING

To ascertain the position of a ship at sea by keeping account of the courses and distances which she sails, or by "dead-reckoning," we proceed on the theory that small sections of the surface of the earth are flat. The whole matter then resolves itself into the solution of right-angled triangles. A single glance will show the student that any of the courses ruled on the diagram chart unite with the parallels and meridians in forming series of right-angled triangles. The only cases in which no such triangles exist are those of sailing due east and west or due north and south.

The problems to be solved in sailing on

the open sea out of sight of land are these: Having left a known point and sailed so many miles in such and such direction, what latitude and longitude have we arrived at,

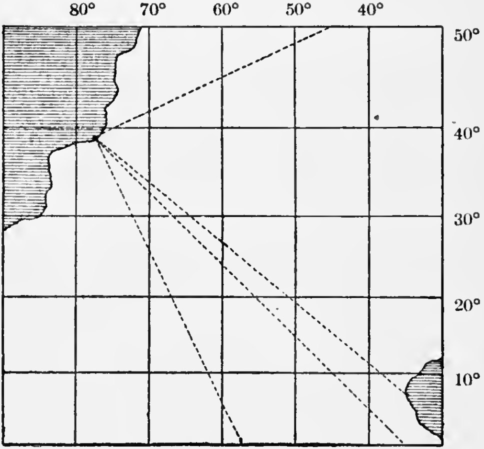


DIAGRAM CHART

and what are the course and distance thence to our point of destination?

If you are sailing due north or south, the problem is extremely simple. Suppose your position at noon to-day is lat. 41° 15′ N., long. 40° W., and up to noon to-morrow you sail 280 miles north (true). It is obvious that the longitude will remain unchanged.

The latitude will be 280 minutes, or 4° 40′, farther north. That 4° 40′ is called the difference of latitude, and in this case it is obviously to be added to to-day's latitude, because we have been increasing our latitude. The ship's position at to-morrow noon, then, is lat. 45° 55′ N., long. 40° W.

The distance by which a ship changes her latitude north or south is called *difference of latitude.*

Let us, then, formulate the rule.

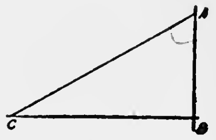
To find the new latitude.—If the old latitude (called latitude left) and the diff. lat. are of the same name (both N. or both S.) it is obvious that you are increasing your latitude. Therefore add and name sum N. or S. after the old latitude. If lat. left and diff. lat. are of different names you are decreasing your latitude. Hence subtract and name accordingly. In either case you obtain the new latitude, sometimes called *lat. in.*

In sailing due east or west, however, the matter is not so simple, because only on the equator are a nautical mile and a minute of longitude the same thing. But if we have a table giving us the number of miles in a degree of longitude at every distance north or south of the equator (which means in every latitude), we can easily find the longitude. For instance, a ship in lat. 42° N. sails true east 100 miles; how much does she alter her longitude? A degree of longitude in lat. 40° measures 44.59 miles. She changes her longitude by 2° 10.8′ or 2° 10′ 48″—a tenth of a minute being 6″.

The number of *miles*, then, which a ship makes east or west is called *departure*, and it must be converted into degrees, minutes, and seconds in order to find the difference of longitude.

But nine times out of ten a ship sails a diagonal course. Suppose a vessel in lat. 40° 20′ N., long. 60° 15′ W., sails 53 miles S.W.-by-W.½W. How are we to find her new latitude and longitude? She has sailed a course like this:. Suppose we draw a perpendicular line to represent a meridian, and a horizontal one to represent a parallel. Then we shall have the triangle ABC, in which the line AC represents the distance and direction, while the angle at A is the angle of the course with the meridian.

If now we can ascertain the length of AB, or the distance by which she has gone to the south, we shall have the difference of latitude; and if we can get the length of the line BC, we shall have the departure and from it the difference of longi-



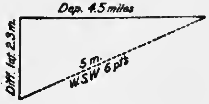
tude. From these two factors we get the new latitude and longitude.

This is a simple problem in trigonometry, but no navigator need know trigonometry, because Tables 1 and 2 of Bowditch solve all possible problems of this kind for him, and he needs only arithmetic.

The complete Navigation Tables can be purchased separate from the rest of the work, under the title *Useful Tables*, for $2.25.

Table 1 is marked at the top with the different courses from ¼ point up to 4 points. In three adjoining columns are found distance, difference of latitude, and departure, marked Dist., Lat., and Dep. If you are sailing on any particular course, say N.N.E., you go to the table for 2-point courses, look in the distance column for the distance you have made by your log, and opposite to that distance you will find your diff. lat. and dep.

At 4 points diff. of lat. and dep. become equal, because the course is precisely half-way between no points and 8 points. On any course *less* than 4 points diff. lat. is greater than dep., because you go more north or south than east or west. On any course *greater* than 4 points dep. is greater than



diff. lat., because you go more east or west than north or south. And the relations of the two elements are simply reversed, as may be seen by the diagrams. In a 2-point course, the diff. lat. is the same as the dep. in a 6-point course, the complement of a 2-point course. Hence, in using the tables, as soon as you have a course over 4 points, you begin at the last page of the tables and read *up* from the bottom, noting that while *dist.* remains in the same place, lat. and dep. are reversed.

Suppose you have sailed 28 miles N.-by-W.¼W. Opposite 28 in the dist. column under 1¼-point courses you find diff. lat. 27.2 miles and dep. 6.8 miles.

(A tenth of a degree (or an hour) is six minutes; a tenth of a minute, six seconds. It is generally convenient to work with these decimals.)

Suppose you have sailed 40 miles E.-by-N. Under 7-point courses (reading from the bottom up) you find opposite dist. 40, diff. lat., 7.8, dep., 39.2.

Table 2, Bowditch, contains the same elements worked for courses in degrees. You should now be prepared to work such examples as these:

A ship leaving lat. 36° 15′ N., long. 47° 48′ W., sails S.E.-by-E. 78 miles. Required the diff. lat., the dep., and the new lat.

Ans. Diff. lat. 43.3, dep. 64.9, new lat. 35° 31′ 42″ N.

A ship leaving lat. 28° 15′ S., long. 43° 18′ E., sails 49 miles N.W. What are the diff. lat., dep., and new lat.?

Ans. Diff. lat. 34.6 miles, dep. 34.6, new lat. 27° 40′ 24″ S.

A ship leaving lat. 1° 10′ N., long. 16° 5′ W., sails S.S.E. 168 miles. Give same elements.

Ans. Diff. lat. 155.2 miles, dep. 64.3 miles, new lat. 1° 25′ 12″ S.

A ship leaving lat. 15° 15′ N., long. 121° 31′ E., steers 63°, 64 miles. Give same elements.

Ans. Diff. lat. 29.1, dep. 57, new lat. 15° 44′ 6″ N.

To find the new longitude.—First find the diff. long by converting dep. into it. First compute the latitude lying half-way between that of yesterday and that of to-day. This is called the middle lat. Go to the page in Table 2 marked with the number of degrees of this mid. lat. which you have just found, and seek in the *diff. lat.* column for the amount of your *dep.* Opposite to it in the *dist.* column will be the figures indicating the number of *minutes* in the *diff. long.*

Example: A ship in lat. 36° 15′ N., long. 52° 18′ W., sails N.E.-by-N. 60 miles; required the lat. and long. in.

Table 1, under the head of 3-point courses, gives for 60 miles diff. lat. 49.9 miles, dep. 33.3. The lat. in is, therefore, 37° 4′ 54″ N. To find the mid. lat. add the lat. left and the lat. in, and divide by 2. Take the nearest degree as your answer. In this case the mid. lat. is 36° 39′ 57″, and as that is nearer 37° than 36° we take the former. Now turn to the page for 37° in Table 2. Apply the dep. 33.3 in the lat. column; the nearest you can come to it is 33.5, opposite which in the dist. column is 42, which means that in lat. 37° a dep. of 33.5 miles will equal 42′ diff. long. Long. left was 52° 18′ W. We have made 42′ diff. long. to the eastward, thus diminishing our westerly longitude. We subtract 42′ from 52° 18′ W., and get 51° 36′ W. as our long. in.

This process of working out the latitude and longitude is called *middle latitude sailing*, and by it the ordinary problems of dead-reckoning are solved. The cases which present themselves in the actual practice of navigation are three in number.

Case I.—Course and distance sailed being given, to find the diff. lat. and dep.

Case II.—The lat. and long. left and the course and distance being given, to find the lat. and long. in.

Case III.—The latitudes and longitudes of two places being given, to find the course and distance between them.

Cases I. and II. have been explained, except as to sailing true east or west, which is called *parallel* sailing. Here there is no diff. lat., and the lat. in is the mid. lat. To find the diff. long. apply the distance sailed, which in this case is also the departure, in the lat. column, and opposite it in the dist. column will stand the number of minutes in the diff. long.

To solve case III.—Subtract the less latitude from the greater, and reduce the remainder to minutes. Do the same with the two longitudes. Find the mid. lat. Go to the page in Table 2 marked with the number of degrees in the mid. lat., and seek the diff. long. in the dist. column. Opposite to it in the lat. column will be the dep. Now seek in Table 2 for the page where the diff. lat. and the dep. stand beside one another in their respective columns. The required dist. will stand opposite in the dist. column, and the course either at the top or bottom of the page, according as diff. lat. or dep. is the greater.

Remember that in working mid. lat. you will know either your departure *or* your diff. long. without looking in the table, but not both. The one you need is always opposite the one you have.

Dep. in lat. col. = Diff. long. in dist. col. (and *vice versa*). In using Tables 1 and 2, if the dist., lat., or dep. in your problem is larger than any found in the table, divide the elements by 10, because the relations of all the parts of a right-angled triangle one-tenth the size of yours will be just the same if you reduce all three sides to one-tenth. For instance, you have diff. lat. 304′; dep. 2694 miles. Divide both by 10 and you have 30.4 and 269.4, both of which are in the tables. With those you can find one-tenth of your distance, which take out and multiply by 10. The angles all remain the same, so the course is all right as it stands.

Example: A ship in lat. 42° 3′ N., long. 70° 4′ W., is bound for St. Mary's, lat. 36° 59′ N., long. 25° 10′ W. What are the course and distance?

Lat. left..........	42° 03′ N.	Long. left.........	70° 04′ W.
Lat. sought.......	36° 59′ N.	Long. sought	25° 10′ W.
Diff. lat..........	5° 04′	Diff. long..	44° 54′
Reduced to minutes =	304	Reduced to minutes =	2694
Middle lat.........	39° 31′		

As the tables do not run beyond 300 miles, we take one-tenth of 2694 (the diff. long.), 269, and under 40° with this number in the dist. column we get 206.1 dep. out of the lat. column. Now we look for a place where the diff. lat. is 30.4 and the dep. 206.1. As we are working with one-tenth of the dep., we must do the same with 304, the diff. lat., or, in other words, put a decimal mark before the 4, making it 30.4. We find under the head of 7¼ points diff. lat. 30.7, dep. 206.7, and opposite them the dist. 209. This is one-tenth of the real distance, 2090 miles. As the diff. lat. was southward and the diff. long. eastward, the course must be S. 7¼ points E., E.¾S., or 98°.

EXAMPLES

What are the course and distance from the Cape of Good Hope, lat. 34° 22′ S., long., 18° 24′ E., to St. Helena, lat. 15° 55′ S., long. 5° 45′ W.?

Ans. Course, 310°. Dist., 1711 miles.

A ship from lat. 2° 05′ N., long. 22° 30′ W., sails W.S.W. 768 miles. Required her new lat. and long. and the course and dist. to St. Ann's Island, lat. 2° 15′ S., long. 43° 38′ W.

Ans. Lat. 2° 49′ S., long. 34° 24′ W. Course, 274°. Dist., 559.6 miles.

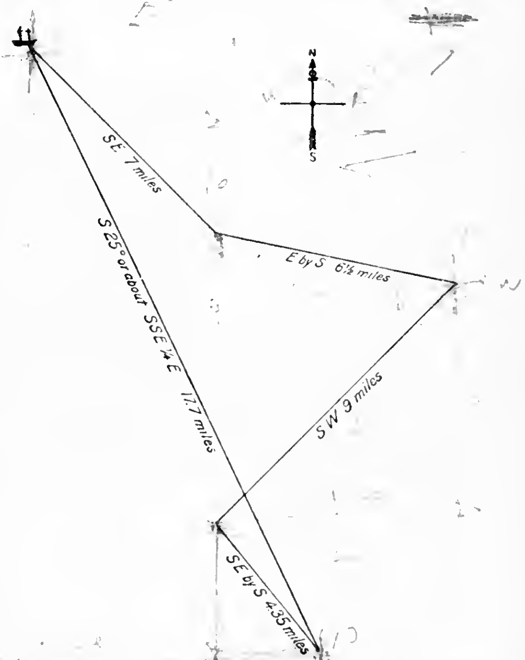
WORKING A TRAVERSE

If a vessel sailed 24 hrs. on one course, the student would not be ready to compute her dead-reckoning. But since the course is changed frequently, it is necessary to obtain the component of several courses. The method of doing this is called working a traverse.

Suppose a vessel to start from Sandy Hook lightship, lat. 40° 28′ N., long. 73° 50′ W., and sail in 24 hours S.E. 7 miles, E.-by-S. 6½ miles, S.W. 9 miles, and S.E.-by-S. 4.35 miles; where would she be at noon on the second day? The diagram shows us that she would be 17.7 miles about S.S.E. $\frac{1}{4}$E. of the lightship.

The method of calculating such a compound course or working a traverse is as follows:

Write out the various courses with their



TRAVERSE COURSE FROM SANDY HOOK LIGHTSHIP corrections for variation, leeway, and deviation, and the distance run on each. In four columns headed respectively N., S., E., W., put down the diff. of lat. and dep. for each course. Add together all the northings, all the southings, all the eastings, all the westings. Subtract to find the difference between northings and southings, and you will get the whole diff. lat. The difference between eastings and westings will give the whole dep.

With the whole diff. lat. and whole dep., seek in Table 2 for the page where the nearest agreement of lat. and dep. with your figures can be found. The number of degrees at the top or bottom of the page (according as diff. lat. or dep. is greater) will give you the *course made good.* The distance made good is found in dist. column, opposite the agreeing lat. and dep.

Find the lat. in, as already explained.

Find the long. in, as already explained.

Example: A ship in lat. 31° 15′ N., long. 68° 30′ 15″ W., sails by compass 36 miles E.-by-S., with 1 pt. W. var., ¼ pt. E. dev., ½ pt. port-tack leeway; 22 miles S.S.E. with same variation, ½ pt. E. dev., ¼ pt. starboard-tack leeway; 28 miles S.-by-E. with same variation, ¼ W. dev., ¼ pt. port-tack leeway; and 31 miles S. with ¾ pt. W. var., ½ pt. E. dev., and ¼ pt. port tack leeway. Required the course and distance made good and the new lat. and long.

Ans. Course, 145°. Dist., 99 miles. Lat. 29° 53′ 54″ N., long. 67° 23′ 15″ W.

In this example there is no subtraction of southing and northing, or of easting and westing. Let us suppose a case, however, of a ship beating to the eastward, and forced to run off to the northwest by some accident. Omitting the corrections of the compass course for the sake of brevity, we should have a traverse like this:

Lat. left, 26° 30′ N.			Long. left, 48° 25′ W.		
Course	Distance	N.	S.	E.	W.
S.S.E.	12	..	11.1	4.6	..
N.E.¼E.	16	10.7	..	11.9	..
S.E.½E.	14	..	8.9	10.8	..
W.N.W.	13	5.0	..	..	12.0
		15.7	20.0	27.3	12.0
			15.7	12.0	
			4.3	15.3	

Course S. 74° E. Distance, 16 miles.

Lat. left.....	26° 30′ 00″ N.	Long. left........	48° 25′ W.
Diff. lat.....	4′ 18″ S.	Diff. long........	17′ E.
Lat. in......	26° 25′ 42″ N.	Long. in.........	48° 08′ W.

Currents.—In case of a known current setting directly opposite to the ship's course, multiply the rate of the current per hour by the number of hours you are in it, and subtract the amount from the amount registered by the log on that course. If the current goes directly with the ship, add the product of its rate by the time. In case of a current setting *across* the ship's course, enter the direction of the current in the traverse as a course and the product of rate by time as a distance.

Example: A ship from lat. 36° 15′ S., long. 101° 14′ E., sails in 24 hrs. 30 miles N.N.W. true and 68 miles W.½N. true. During 12 hrs. of the day she is in a current setting E.½S. at the rate of 2 knots per hour. Required her course and distance made good.

Course	Distance	N.	S.	E.	W.
N.N.W.	30	27.7	. .	. .	11.5
W.½N.	68	6.7	. .	. .	67.7
E.½S.	24	. .	2.4	23.9	. .
		34.4			79.2
		2.4			23.9
		32.0			55.3

Ans. Course made good, N. 60° W., or 300°, dist. 64 miles.

HOVE TO

A vessel hove to in a gale comes up toward the wind and then falls off, and her course is a zigzag. To keep her reckoning note how she heads when she has come up as far as she will, and again when she has fallen off to the limit. The point half-way between is to be called the course. For instance, she comes up to east and falls off to northeast. The course is east-northeast.

The leeway, variation, and deviation are applied to the course thus ascertained. Different ships make different leeway, and the navigator must determine its extent by careful observation.

Every time she begins to come up she will go ahead a little. The speed of this progress or "drift" is entered as the rate in knots. The rest of the operation is the same as in working a traverse.

Example: A vessel in lat. 33° 14′ S., long. 60° 47′ E., is hove to on the starboard tack. She comes up to E.-by-S., and falls off to E.-by-N.; leeway, 6 points; drift, 2 knots per hour; variation, 22° E.; no deviation; vessel hove to 24 hours. What is her position at noon of the second day?

Ans. Lat. 32° 40′ S., long. 61° 27′ E.

THE DAY'S RUN

It is customary to enter in the log-book the position of the ship at noon by D. R. as well as by observation, and the day's run is therefore worked up in traverse form. Where observations fix new positions, disagreeing with the D. R. (either lat. or long. or both) the D. R. is disregarded in continuing the work and begun again from the position obtained by observation.

Example (worked for 12 hours only).—Mar.

Time	C. C.	Var.	Dev.	T. C.	Pat. Log	Dist.	N.	W.	Diff. Long.
8 A.M.					126.5				
Noon	285°	− 15°	+ 4°	274°	185.2	58.7	4.1	58.9	68′
4 P.M.	315°	− 15°	+ 7°	307°	246.6	61.4	36.7	48.7	57′
8 P.M.	310°	− 12°	+ 5°	303°	296.8	50.2	27.2	41.9	49′

Lat. left	30° 15′ N.
To noon diff. lat.	4′ N.
Noon lat. by D. R.	30° 19′
Noon lat. by obs.	30° 26′ 00″ N.
Diff. lat. to 4 P.M.	36′ 42″ N.
Lat. by D. R. 4 P.M.	31° 02′ 42″ N.
Diff. lat. to 8 P.M.	27′ 12″ N.
Lat. by D. R. 8 P.M.	31° 29′ 54″ N.

Long. left	46° 28′ W.
To noon diff. long.	1° 8′ W.
Noon long. by D. R.	47° 36′ W.
Diff. long. to 4 P.M.	57′ W.
Long. D. R. 4 P.M.	48° 33′ W.
Long. by obs. 4 P.M.	48° 38′ W.
Diff. long. to 8 P.M.	49′ W.
Long. D. R. 8 P.M.	49° 27′ W.

The traverse shown herewith is the full navy form as now used.

9, 1918. At sea. 8 A.M. sight, worked with D. R. lat. 30° 15′ N. gave long. 46° 28′ W. From 8 A.M. to noon ship sailed on 285° course. Var. 15° W., dev. 4° E. Pat. log reading, 8 A.M., 126.5; at noon, 185.2. Noon sight gave lat. 30° 26′ N. From noon ship sailed on 315° course, same var., dev. 7° E., till 4 P.M., when Pat. log read, 246.6. Time sight gave long. 48° 38′ W. From 4 to 8 P.M. ship sailed 310°, var. 12° W., dev. 5° E. Pat. log at 8 P.M., 296.8. Required D. R. position of ship at 8 P.M. (See page 54.)

SHAPING THE COURSE

Having ascertained the position of the ship, it becomes necessary to ascertain the course required to sail to reach the port of destination. This may be done by using the chart, if the distance is small and the scale of the chart large. If the distance is considerable and the scale of the chart small, much inaccuracy will follow. Therefore the course is found by mid. lat. or Mercator's sailing. For mid. lat. method see Case III. of dead-reckoning.

The course will be correct only when the distance is small. For a long course use Mercator's sailing. In crossing the equator treat the parts of the course N. and S. of it separately.

For Mercator's sailing we use Table 3. This table contains the meridional parts corresponding to the increase of the length of degrees as we go toward either pole on a Mercator's chart. Find required merid. parts by applying degrees at top of table, minutes at side. Merid. parts for 19° 45′ are 1201.4; 9° 36′, 574.9; 29′, 28.8.

To determine course and distance.—Find the merid. parts of lat. in and lat. sought. Difference between them is called meridional diff. lat. This is used *only in finding the course*, by seeking in Table 2 for page where merid. diff. lat. stands opposite the diff. long., former in the lat. and latter in dep. column. Course in degrees at top or bottom of page. Under this course apply proper (*not* merid.) diff. lat. in the *lat.* column, and find the required dist. opposite to it in dist. col.

Example: What are the course and distance from Sandy Hook Lightship, lat. 40° 28′ N., long. 73° 50′ W., to lat. 30° 51′ N., long. 72° 45′ W.?

Lat. in	40° 28′	Mer. parts	2644.5
Lat. sought	39° 51′	Mer. parts	2596.2
Proper diff. lat	0° 37′	Mer. diff. lat	48.3
Long. in	73° 50′ W.		
Long. sought	72° 45′ W.		
Diff. long	1° 05′ = 65′		

On the page in Table 2 which has 37° at the top and 53° at the bottom we find

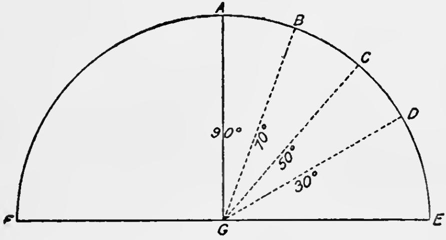
64.7 and 48.7 opposite one another. This is the nearest agreement to the meridional diff. lat. and the diff. long. that we can find. As the 48.7 is in the right-hand column we must read the table up from the bottom, and this gives us a course of 127° or S. 53° E. Applying our proper diff. lat., 37′, in the lat. column we find 37.3, opposite which is the dist., 62 miles.

Courses obtained by computation are true, and must be corrected for variation and deviation. Get the variation from the chart and then for the magnetic course obtain the deviation from the Napier curve, explained under *Compensation of Compasses.*

NAVIGATION BY OBSERVATION

Navigation by observation is carried on by measuring the altitude of the sun, the moon, or a star, and computing from this and certain other data the latitude or longitude of the ship. The altitude of a celestial body is expressed in terms of degrees and minutes, and is that part of 90° contained between the body and the sea horizon.

An observer standing at the point G in the diagram would see the horizon at E and F, and the apparent sky stretching from one side to the other in a semicircle, or rather hemisphere. Now a circumference of this semicircle is divided, like any other, into 180°. Supposing the sun to rise at E, at D it would be 30° high, at C 50°, at B 70°, and at A, immediately overhead, 90°. Going down the other side its altitude would continually decrease. From this we learn that the altitudes of celestial bodies range from 0 to 90°, for no matter in which direction we face the horizon the arc of the sky



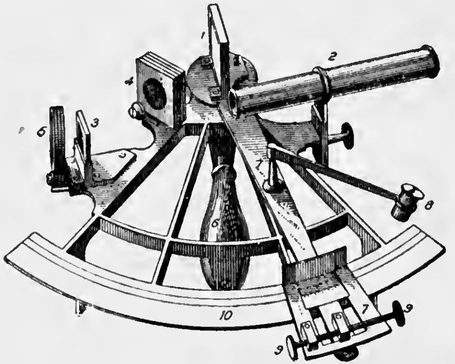
from the horizon point opposite us to the zenith, which is the point immediately overhead, will measure 90°.

THE SEXTANT

The first element, then, required in any problem of navigation by observation, is the angular altitude of the celestial body in use. The measurement of this altitude is made by means of the sextant, or an instrument of the sextant family.

The principal parts of the sextant are shown in the accompanying sketch.

The sliding limb (No. 7) has a clamp sliding along the arc (No. 10). A screw passes through this clamp, and by tightening it

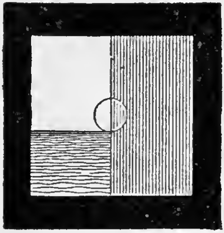


SEXTANT

1. Mirror.
2. Telescope.
3. Horizon-glass.
4. Shade-glasses.
5. Back Shade-glasses.
6. Handle.
7. Sliding limb.
8. Reading-glass.
9. Tangent screw.
10. Arc.

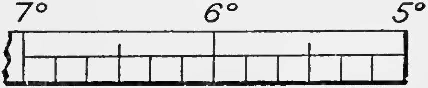
the sliding limb is held firmly in any position at which it is placed. It can, however, be further moved by very small advances by the use of the tangent screw (No. 9).

The instrument is held by the handle (No. 6) in the right hand, with the telescope toward the observer's eye. He must now direct the telescope toward that part of the sea which is directly beneath the celestial object to be observed. His line of sight will pass through the horizon-glass. He now moves the sliding limb until the image of the celestial body, reflected by the mirror (No. 1) appears in the horizon-glass. He then tightens the clamp screw, described above, and by means of the tangent screw (No. 9) moves the sliding limb just a little more, so that the image "kisses" the horizon, which is seen through the transparent half of the horizon-glass. If he can make the image split on the two halves of the glass, as in the cut, the "contact," as it is called, will be all the more accurate. He now reads the angular altitude from the scale on the arc of the sextant by means of the reading-glass. The measurement is shown by a small vernier scale which runs along the oblong opening in the sliding limb.

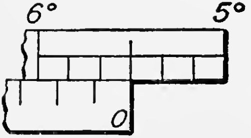


HORIZON-GLASS WITH SUN "KISSING SEA"

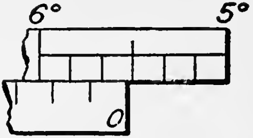
The arc itself is divided into degrees and sixths of a degree in this manner:



The vernier is divided similarly, but its parts represent minutes and sixths of a minute. To read the angle the zero point on the vernier is used as a starting-point. If it exactly coincides with one of the lines on the scale of the arc, that line gives the measurement of the angle; thus, in this case the angle is 5½°, or 5° 30′.



If, however, you find the zero point has passed a line of the arc, as in the second case shown, your angle is more than 5° 30′, and you must look along the vernier to the left till you find the point where the lines do coincide. Then add the number of minutes and sixths of a minute shown on the vernier between zero and the point of coincidence to the number of degrees and minutes shown on the arc at the line which the vernier zero has passed, and the sum will be the angle measured by the instrument.



Some instruments have the arc cut to quarters of a degree, or 15′, and a quadrant is cut to thirds of a degree, the vernier showing minutes only. The sextant is the instrument most in use. The student will require some practice before being able to take and read an altitude of the sun, and a great deal before he can do anything with the stars. An hour's practice under an old mariner, however, will do him more good than a hundred pages of book instruction.

Regulate the shade-glasses to suit your eye. Those at the top of the instrument affect the image of the sun only, and serve to deaden its brilliancy. The back shade-glasses are used when the glare on the water is too powerful. You cannot get a good contact with your eyes dazzled.

SEXTANT ADJUSTMENTS

I. The mirror must be perpendicular to the plane of the instrument. Set the sliding limb at 60°. Hold the sextant face up, with the arc away from you. Place the eye nearly in the plane of the instrument opposite the apex and look into the mirror. If the image of the arc in the mirror and the arc itself show in one unbroken line, the adjustment is correct; if the reflected image is lower, the glass leans backward; if it is higher, the glass leans forward. Straighten the glass by turnin the screws at its back.

II. The horizon-glass must be perpendicular to the plane of the instrument. Set the zero of the vernier to the zero of the arc. Hold the sextant almost face upward, and look through the sighting-vane and the horizon-glass at the horizon. If the horizon line and its image (seen in the clean and silvered parts of the glass) do not coincide, turn the screw at the back of the glass till they do.

III. The horizon-glass must be parallel to the mirror. Set the zero of the vernier to the zero of the arc. Hold the instrument as in taking an observation, and look at the horizon. If the line and its image in the silvered part of the horizon-glass coincide, the adjustment is correct; if they do not show in an unbroken line, adjust the horizon-glass by turning its screw.

IV. The line of sight of the telescope must be parallel to the plane of the instrument. "Screw in the telescope containing the two parallel wires, and see that they are turned until parallel with the plane of the sextant; then select two stars, at least 90° apart, and make an exact contact at the wire nearest the plane of the instrument, and read the measured angle. Move the sextant so as to throw the objects on the other wire, and if the contact is still perfect, the axis of the telescope is in its right situation and the telescope adjustment is correct. If the images have separated, it shows that the object end of the telescope droops toward the plane of the sextant, and if the images overlap, it proves that the object end of the telescope points away from the plane of the instrument. This will be rectified by the screws in the collar of the sextant. A defect in the telescope adjustment always makes angles too great" (Patterson).

INDEX ERROR

It is better to have the adjusting done by a professional instrument-maker. Then let the sextant alone. Error remaining after adjustment is called index error. It is found thus: Set the sliding limb at o, hold the instrument perpendicularly, and look at a star. Move the sliding limb forward or backward till the star and its image coincide in the horizon-glass. Clamp the sliding limb and read the angle, which is the index error. If zero on the vernier is to the left of zero on the arc, the index error is to be subtracted; if it is to the right, the error must be added. By the sun.—Aim sextant right at the sun. Make a contact of sun's image with top of sun, and read angle. Make contact of image with bottom of sun and read angle. One reading will be off the arc and is marked +, the other on the arc, marked −. Half the difference between the two, marked with sign of greater, is the error. Index error is usually expressed thus: I. E. 1° 15′ −; or

I. E. 2° 8′ +. The horizon and its image brought into line can also be used.

HINTS ON TAKING ALTITUDES

Learn to take a single sight with accuracy. It is a good thing to take the mean of three or four sights when working longitude, but you cannot always do that.

Oscillating the instrument from right to left and back, while taking a sight, will make the image skim the horizon so that you may make sure of the point vertically under it.

When fog obscures the horizon from the deck, you can sometimes get a new horizon by lowering yourself away in a boat.

In rough weather try to get the mean of three or four sights. You thus reduce the amount of error caused by the pitching of the ship.

Ascertain the index error before taking every altitude or set of altitudes. The error is liable to change.

CORRECTING THE ALTITUDE

Certain corrections have to be made to all altitudes taken with a sextant. These corrections are for dip of the horizon, refraction, and in the cases of the sun and moon, for semi-diameter.

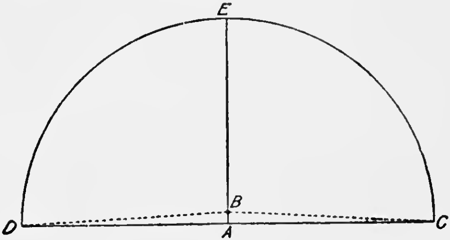
The altitude used in the computation of the ship's position is that of the center of the celestial body. As already explained, the sextant gives the altitude of the upper or lower edge.

For practical purposes we assume that the diameter of the sun equals 32′ of the arc of the sky. Therefore, if you take the altitude of the lower edge you must add 16′, or half the diameter, to get the altitude of the center. If you take the altitude of the upper edge, as you might have to do in case the lower one was obscured by clouds, you must subtract 16′. Stars, having no apparent diameter, do not call for this correction.

Dip of the horizon means an increase in the altitude caused by the elevation of the eye above the level of the sea. The simplest illustration of this is afforded by the accompanying figure. If the eye is on the level of the sea at A, it is in the plane of the horizon CD, and the angles EAC and EAD are right angles, or 90° each. If the eye is elevated above A, say to B, it is plain that the angles EBC and EBD are greater than right angles, or, in other words, that the observer sees more than a semicircle of the sky and hence his measurements are too large. Therefore the correction for dip is *always subtracted* from the altitude.

Dip is proportionate to the height of the eye above the water. Table 14 gives the necessary corrections. The navigator must ascertain the height of his eye above the ship's water-line.

Dip is subject to variations. Much difference between temperature of the air and that of the water displaces the horizon. Increase in temperature increases the tabulated



corrections. Increase in wind diminishes them. Sea water colder than air, horizon raised, dip decreased; water warmer, horizon depressed, dip increased.

Error decreases as height of eye increases. When error is likely, take alt. from highest point available.

Alt. can be taken against a shore line closer to ship than sea horizon would be. For this use Table 15.

Refraction is the curving of the rays of light caused by their entering the earth's atmosphere, which is a denser medium than the impalpable ether of the outer sky. The effect of refraction is frequently seen when an oar is thrust into the water and looks as if it were bent.

Refraction always causes a celestial object to appear higher than it really is. This phenomenon is greatest at the horizon and diminishes toward the zenith, where it disappears. Table 20 gives the corrections for mean refraction, which are always subtracted from the altitudes. In the higher altitudes, select the correction for the nearest degree.

Avoid taking low altitudes (15° or less) when the atmosphere is not perfectly clear. Haziness increases refraction. If compelled to take a low altitude when there appears to be more than the normal amount of refraction, correct the refraction for the height of the barometer by Table 21, Bowditch.

Table 46 gives all corrections (except I. E.) in one.

Example: At sea, June 27, 1918, observed meridian alt.: ☉ (this sign stands for the sun; * for a star) 67° 26′ 15″; index error, + 15′; height of eye, 25 ft. Required, T. C. A. (true central altitude).

Obs. alt. ☉	67° 26′ 15″
I. E.	+ 15′ 00″
	67° 41′ 15″
Semi-diam	+ 16′ 00″
	67° 57′ 15″

Dip	− 4′ 54″
	67° 52′ 21″
Refraction	− 23.6″
T. C. A.	67° 51′ 57.4″

In actual sea practice work this way:

Obs. alt.	67° 26′ 15″	I. E.	+ 15′ 00″
Correction	+ 25′ 43″	Table 46	+ 10′ 43″
T. C. A.	67° 51′ 58″		+ 25′ 43″

THE CHRONOMETER

The chronometer is simply a finely made and adjusted timepiece placed in a box and swung in gimbals, as a compass is, to prevent it from being injured by the motion of the ship.

The care of a chronometer is not essentially a part of the science of navigation, but in practice the navigator has to use and care for his own chronometers, and the author has, therefore, in the latter part of this book, given some suggestions as to the proper treatment of these instruments.

The purpose of the chronometer aboard ship is to register Greenwich time. English and American navigators reckon their longitude east or west from the Greenwich meridian, and, as we shall learn further on, the computation of longitude consists in ascertaining the difference between the time at Greenwich and the time at the ship.

The secondary reason for carrying a chronometer is that the astronomical data contained in the Nautical Almanac are all given for the Greenwich time. Hence:

Always note the chronom. time of an observation.

Every chronometer gains or loses a little time every day. When in port the instrument is taken to a maker, who regulates it and ascertains its *daily rate* of losing or gaining. On returning it to the owner, the maker furnishes a memorandum stating that on such and such a date the chronometer was so many minutes and seconds faster or slower than Greenwich time, and was losing or gaining so much a day.

The navigator, therefore, must correct the time shown by the chronometer by adding or subtracting the original error + daily gain or loss, thus:

Example: Chronometer on Oct. 11 showing 2 h. 15 m. 27 s., was 3 m. 20 s. slow of Greenwich mean time (G. M. T.) on Oct. 1, and its daily rate is 0.8 sec. losing. What is the G. M. T.?

Ans. Oct. 1 to 11 = 10 days; 0.8 × 10 = 8 sec. loss. On Oct. 11 chronom. is 3 m. 20 + 8 s. slow.

Chronom. time........................	2 h. 15 m. 27 s.
Correction...........................	+ 3 m. 28 s.
G. M. T..............................	2 h. 18 m. 55 s.

Always make the chronom. correction, otherwise dangerous error may ensue.

In practice a hack watch is used in taking sights, its time having been compared with that of the chronom. The difference is designated C.-W., and is easily applied.

THE NAUTICAL ALMANAC

The Nautical Almanac is a compendium of data computed by the government astronomers for the solution of the problems of navigation by observation.

The first contents demanding the student's attention are the pages containing the declination of the sun and the equation of time for every two hours of each day in the year.

Declination is celestial latitude. For astronomical purposes we locate an equator in the heavens directly above the earth's equator. The celestial north pole is right over our own. From equator to either pole, whether terrestrial or celestial, is 90°. A celestial body with a dec. of 20° is 20° N. of the equator. A star directly over the head of a man standing on the deck of the Sandy Hook Lightship, lat. 40° 28′ N., would have a dec. of 40° 28′ N.

Because the axis of the earth is at an angle with its orbit around the sun, the sun apparently moves to the north in summer and south in winter.

The extreme limits of the sun's declination are 23° 27′ 30″ north and south. The former point is reached June 21—our longest day—and the latter Dec. 21. Half-way between these dates the sun crosses the equator going south. Hence, from June 21 to Sept. 21, the sun's dec. is N. and always *decreasing*. From Sept. 21 (or 22) till Dec. 21, the dec. is S. and increasing. From Dec. 21 to Mar. 21 the south dec. decreases, and from some time on Mar. 21 the sun has N. dec., increasing. Remembering these points, you can never be in doubt as to whether dec. is N. or S.

To ascertain the dec. for any time and at what rate it changes—an important point —the navigator consults the Nautical Almanac (N. A.). Here is a reproduction of part of a page, giving the data for the dec. and the equation of time (to be explained later).

Facsimile of Part of Nautical Almanac
October, 1918

G. M. T.	Declination	Equation of Time	
	Thursday	, 17.	
h.		m. s.	
0	− 9° 3′.5	+ 14 27.0	
2	9 5 .4	14 28.0	
4	9 7 .2	14 29.1	
6	9 9 .0	14 30.1	
*	* * *	* * *	
H.D.	0 .9	0.5	

The – sign before dec. means that it is south; a + means north. Similar signs before the equation, however, mean add or subtract in applying to mean time. The dec. is given for every two hours. H. D. signifies hourly difference and applies to the figures immediately opposite to it. If you take an observation at a time not given in the N. A., select the nearest hour and apply the given H. D. or fraction thereof. If the given hour, let us say, is 4 P.M., and the time of your observation is 4 h. 30 m., you will need to add half of the H. D. to the given dec. if the dec. is *increasing*, and subtract if the dec. is *decreasing*. Note carefully whether it is increasing or decreasing. Or keep in mind the process of increase and decrease as above described.

In consulting the column marked G. M. T., note that the almanac records *astronomical* time, which begins at *noon* and is counted through 24 hrs., coinciding with the day of a ship's run at sea. Thus 10 A.M. of June 12 is 22 o'clock of June 11 in the N. A.

Example: At sea, Oct. 4, 1918. Chronom. time (corrected), 3 h. 15 m. 15 s. P.M. Required corrected dec.

Dec. 2 P.M.	4° 10.2′ S.	H. D.	1′
Correction	+ 1.25′	Time after 2	1.25 h.
Cor. dec	4° 11.45′ S.	Cor	1.25′
or	4° 11′28″ S.		

APPARENT AND MEAN TIME—THE EQUATION

Apparent time is that shown by the sun. Mean time is that shown by the clock.

The equation of time is the difference between them.

The earth revolves on its axis once in 24 hours, and theoretically the sun crosses the meridian of any given place at precisely 12 o'clock each day, and it is then noon. As a matter of fact this is not so. The earth does not revolve at a uniform rate of speed, and consequently sometimes the sun is a little ahead of time and again it is behind.

Now you cannot manufacture a clock which will run that way. Its hours must all be of exactly the same length, and it must make noon at precisely 12 o'clock every day. Hence we distinguish clock time from sun time by calling the former mean (or average) time and the latter apparent.

Your chronometer shows G. M. T. (Greenwich mean time).

Your cabin clock should show **L. M. T.** (local mean time).

The sun always gives **L. A. T.** (local apparent time.)

Hence, if you wish to add sun time, as ascertained from an observation, to G. M. T., you must convert the former, L. A. T., into L. M. T. by applying the equation of time.

In some operations you must convert G. M. T. into G. A. T., which is also done by applying the equation.

The equation is given in the N. A. with a sign prefixed, showing whether it is to be added or subtracted. Since the figures given in the time column (col. 1) are for G. M. T., these signs + or − show whether the equation is to be added to or subtracted from G. M. T. to convert it into G. A. T. If you already have ascertained apparent time and wish to convert it into mean time, obviously you must reverse the adding or subtracting process.

Always pick out the equation for Greenwich, *not* local time.

The equation is subject, like declination, to hourly variation. This is given at the foot of the column of equations for each day. The equation itself, like the declination, is shown for every two hours of the day at Greenwich.

The equation should be corrected just as the dec. is, preferably by applying the H. D. as given in the N. A.

Do not forget that the time in N. A. begins at noon. Ten o'clock A.M. of Jan. 17 is 22 o'clock of Jan. 16.

An approximate knowledge of your longitude will enable you to determine whether the chronometer, which is marked up to 12 hrs. like an ordinary clock, indicates A.M.

or P.M. time at Greenwich. Turn the long. into time (explained later). In west long. your time must be earlier than Greenwich. In east long. *vice versa.* For example, in round figures New York is 5 hrs. west of G. At 3 P.M. in G. it is 10 A.M. in N. Y. In 5 hrs. east long., your clock showing 3 P.M., it is 10 A.M. or 22 hrs. astronomical at G.

LATITUDE BY MERIDIAN ALTITUDE

A meridian altitude is one taken when the celestial body observed bears true south or north of the observer, or is precisely above the meridian of longitude on which he stands. In the case of the sun this is at apparent noon.

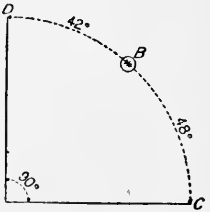
A meridian altitude gives the most accurate latitude, for reasons which will hereafter be explained.

The general formula for a meridian altitude is lat. = zenith distance + or − declination.

Zenith distance is the distance, measured in degrees, from the point precisely over the observer's head to the observed body. Let us suppose that you and the sun are both north of the equator. If now you can ascertain exactly how far you are north of the sun, and how far the sun is north of the equator, you will, by adding the two measurements together, know your latitude.

The declination of the sun, obtained from the N. A. and corrected for chronom. time, as already explained, is the distance of the sun from the equator.

The zenith distance is the difference between the altitude of the sun, taken by the sextant, and 90°. You know that it is 90° from the zenith to the horizon. Hence, having got the altitude of the sun, you have only to subtract it from 90° to find how far you are from the sun. The arc DBC in the diagram measures 90°. If the sun is at B, it is 48° from C, the horizon, and 42° from D, the zenith.



Now if you are 42° north of the sun, and it is 10° north of the equator, you must be 52° north of the equator, or in lat. 52° N.

That is the first and simplest case. Suppose, however, the sun is in south declination, and you are somewhere in north latitude. In that case your distance north of the equator would naturally be the zenith distance minus the declination, because the zenith distance, altitude, and declination together would make an arc of over 90°, and you can't be over 90° north or south of the equator.

Again, suppose that the sun is in 22° south declination, and you are 10° north of the sun. In that case you would have to subtract the zenith distance from the declination to get your latitude, because the sun's latitude is greater than yours. From these considerations we deduce the following rule:

Begin to measure the altitude of the sun with the sextant a short time before noon. The altitude will constantly increase till apparent noon, when it will stop and then begin to decrease. You will be able to detect this by bringing down the image of the sun to the horizon in the horizon-glass and carefully watching it. The highest altitude attained is the one you need. At that instant note the chronometer time.

To work out the lat., call the altitude S. if the sun is south of you, N. if north. Correct the altitude for semi-diam., dip, and refraction as already explained. Subtract the true central alt. from 90° to obtain the zenith dist. If the alt. is S., name Z. D. north, or *vice versa.* Correct the declination for the chronom. time as already explained. If Z. D. and dec. are both N. or both S., add them, and the sum will be the lat. N. or S. as indicated. If one is N. and the other S., subtract the less from the greater, and the answer will be the lat. named N. or S. after the greater.

At sea, June 15, 1918. Obs. merid. alt. ⊙, lower limb, 71° 15′, sun bearing S. Index error − 2′; height of eye, 25 ft.; chronom. 3 h. 28 m. 15 s. P.M.; chronom. slow of G. M. T. 1 m. 50 s. on June 5; daily rate, − .5 sec. Required, lat. of ship.

Obs. alt......	71° 15′ 00″ S.
Correction...	+ 8′ 48″
T. C. A......	71° 23′ 48″ S.
	90° 00′ 00″
Z. D.........	18° 36′ 12″ N.
Cor. Dec.....	23° 17′ 57″ N.
Lat..........	41° 54′ 09″ N.

Cor. Table 46....	+ 10′ 48″
Index Error......	− 2′ 00″
Correction.......	+ 8′ 48″
Hourly diff. dec..	6″
Time after 2 P.M.	1½ hr.
Cor. for dec.....	+ 9″
Dec. 2 P.M....	23° 17′ 48″ N.
Cor. dec......	23° 17′ 57″ N.

At sea, Sept. 25, 1918. Obs. merid. alt. lower limb ⊙, 50° 03′ 00″ S. Index error, + 6′; height of eye, 20 ft. Chronom. 2 h. 15 m. 10 s. P M.; chronom. slow of G. M. T. on Sept. 20, 1 m. 10 s.; daily rate, -- .3 s. Required, lat. of ship.

Obs. alt......	50° 03′ 00″ S.
Cor..........	+ 16′ 54″
T. C. A......	50° 19′ 54″ S.
	90° 00′ 00″
Z. D.........	39° 40′ 06″ N.
Dec.........	40′ 27″ S.
Lat..........	38° 59′ 39″ N.

Cor. Table 46....	+ 10′ 54″
I. E............	+ 6′
Correction.......	+ 16′ 54″
H. D. dec........	1′
Time after 2 P.M..	.25 hr.
Correction.......	.25′ = 15″
Dec. 2 P.M.......	40′ 12″ S.
Cor. dec.........	40′ 27″ S.

Taking meridian altitudes is facilitated by computing the approximate alt. beforehand

and setting it on the sextant. Then when the body approaches the meridian, direct your sextant to the horizon under the body and you will find the image in the horizon-glass. You have now only to make the final contact to get the altitude.

Formula for computing approximate meridian alt. *Very important* to naval students especially, as it is daily in use. The formula is $90° - L. + d = h.$ (alt.). Rule: subtract the lat. by D. R. from 90°. Call remainder co-lat. (complement of lat.) and name it N. or S. as lat. is. Correct your dec. for G. M. T. at noon at ship. If co-lat. and dec. are of same name, add; if of different names, subtract. Answer is approx. alt.

In actual practice at sea so small a correction to the dec. as that in the first example would be ignored. Indeed, except when nearing land or some hidden danger, it is sufficient at sea to know your lat. to the nearest minute. When the chronom. time after or before the nearest hour in the N. A. is small, and the H. D. also small, correction may be omitted.

USE OF LAT. CONSTANT

The foregoing method is the old-established way of working a merid. alt., and continues to be used in the merchant service. In the navy it is the rule to prepare a constant to which the obs. alt. can be applied and the lat. immediately known. The general formula for this constant is

Lat. = 90° + dec. − cor. − obs. alt.

The correction is that for the approx. alt. computed as already explained. We now have these variations of the general formula:

I.—Lat. and dec. same name, lat. greater:
+ 90° + dec. − cor. − obs. alt.

II.—Lat. and dec. same name, dec. greater:
− 90° + dec. + cor. + obs. alt.

III.—Lat. and dec. opposite names:
+ 90° − dec. − cor. − obs. alt.

The constant is computed before the observer goes on deck. When the merid. alt. is obtained, the lat. is found by one addition or subtraction. The first example previously given would be worked thus:

	+ 90° 00′ 00″
Dec.	+ 23° 17′ 57″
Cor.	− 8′ 48″
Constant	113° 09′ 09″
Obs. alt.	71° 15′ 00″
Lat.	41° 54′ 09″ N.

All latitudes by merid. alt. hereinafter will be worked by constant.

The *correction* in the constant must be treated algebraically. It is a quantity with a sign + or −. If the constant says + cor., you add it if its sign is +, and subtract if the sign is −. If the constant says − cor., you subtract it if its sign is + and add it if its sign is −.

LAT. BY MERID. ALT. OF A STAR

You can learn the location of the principal stars from any good star map. The N. A. contains one. The best hours for observing stars are morning and evening twilights, when the horizon is clearly defined. Moonlight nights also bring out a good horizon. Experienced observers can get star altitudes on starlight nights with a first-class sextant and a visible horizon.

Stars are very serviceable when the sun is invisible all day and it clears at night. Stars about to cross the meridian can be found very often; you do not have to wait twenty-four hours.

The declinations of all the stars available for the navigator are to be found in the back part of the N. A., in the star tables. Those marked + are N., those − are S. The *annual* variation of declination is so small that the correction is monthly; hence the chronometer time is not taken, and no allowance has to be made for semi-diameter. With these exceptions the method of working out the lat. by a star's merid. alt. is the same as that for the sun.

Example: At sea, Dec. 7, 1918. At 10.50

P.M. (L. M. T.) took merid. alt. * *Aldebaran* (*α* Tauris) 75° 21′ S.; no index error; height of eye, 20 ft.

	+ 90° 00′ 00″
Dec.	+ 16° 21′ 00″
Cor.	+ 4′ 39″
Constant	106° 25′ 39″
Obs. alt.	75° 21′ 00″
Lat.	31° 04′ 39″

Star corrections in Table 46 are all minus. The formula says subtract the correction. To subtract a minus quantity you must add it.

It is advantageous to know what star to observe at a given hour, or, in other words, what star is about to cross your meridian. For this you must employ the right ascension (R. A.) of the sun and the R. A. of the required star. The meaning of right ascension will be explained later. The R. A. of the mean sun is given for each day and hour in the first pages of the N. A. The R. A. of the star is in the tables of places of fixed stars, latter part of N. A.

Suppose you wish to learn what star will cross your meridian a little after 9 P.M. Add 9 hrs. to the R. A. of mean sun. This gives you the R. A. of your own meridian. If over 24 hrs., subtract 24 hrs. from it. Select from the star table a star having an R. A. a little greater than your own. That will be the next star to cross your meridian.

Example: At sea, Jan. 5, 1918. Wished to get merid. alt. of a star about 10 P.M.

R. A. ⊙	18 h. 57 m. 04 .6 s.
Time at ship................	9 h. 30 m. 00
	28 h. 27 m. 04 .6 s.
	24 h.
R. A. Merid................	4 h. 27 m. 04 .6 s.

The star table shows that Aldebaran has R. A. 4 h. 31 m. 15 s. That is the star you require. It will cross your meridian in 4 m. 10 s., or the difference between R. A. M. and R. A. *.

The star's dec. will tell you whether to seek it N. or S. of you. If you are in lat. N. the star will be S. of you if its lat. is S. or if it is N. and less than your lat. Lat. and dec. both N., dec. greater, star N. of you. Apply the same rule in S. lat.

If you can get two stars, one N. and one S., at about the same time, the lat. will be the mean of the two obtained.

LAT. BY MERID. ALT. OF A PLANET

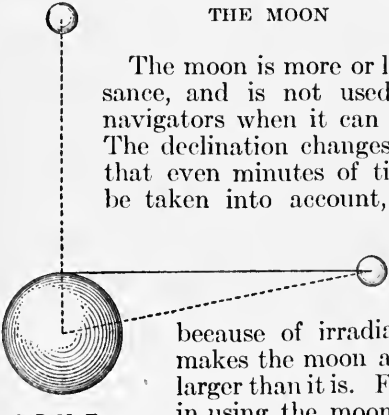
The data for planets follow those for the moon in the N. A. The declinations are given for each day, and the *daily* variation at the right in small figures in tenths of minutes. To save calculation, enter Table IV., N. A., with the daily variation at the top and the G. M. T. of the observation at the side, and take out the number of tenths of minutes to be used as correction for dec. The rest of the work is the same as for a star, except that you must note the chronom. time.

Example: At sea, Feb. 27, 1918. Obs. alt. Saturn, 75° 21′ S. No index error. Height of eye, 20 ft. G. M. T., 10 h. 29 m. 12 s. P.M.

	+ 90° 00′ 00″
Dec......	+ 18° 52′ 30″
Alt. cor...	+ 4′ 39″
Const.....	108° 57′ 09″
Obs. alt...	75° 21′ 00″
Lat.......	33° 36′ 09″ N.

Dec............	18° 52.1′ N.
Cor. Table IV..	.4′
	18° 52.5′ N.

LATITUDE BY MERIDIAN ALTITUDE OF THE MOON



PARALLAX

The moon is more or less of a nuisance, and is not used by expert navigators when it can be avoided. The declination changes so rapidly that even minutes of time have to be taken into account, and one is likely to be deceived as to its semidiameter because of irradiation, which makes the moon at times look larger than it is. Furthermore, in using the moon we have to allow for parallax.

Parallax is the difference in the angular altitude of a celestial body as measured from the surface or the center of the earth. It is greatest when the body is in the horizon, and disappears when it is at the zenith. The sun is so far away that its parallax never exceeds 9″. The stars have practically none at all from the earth's surface. The moon, however, is near enough to make an allowance necessary. On the other hand, it is often visible in daylight and may be used at the same time as the sun to get combined observations (see Sumner method). Also, it lights up the horizon at night, greatly facilitating the navigator's work. Therefore it should be used when helpful, despite the ready liability of the computations to error. The navigator must be especially careful in moon work.

To work a merid. alt. of the moon, note chronom. time of obs. and begin as with a planet, noting particularly, however, that the dec. is given, like the sun's, for every 2 hrs., with the diff. for the same interval. For correction use Table IV., N. A., as with planet.

Take out the horizontal parallax (found in N. A. in column headed H. P.) and with it enter Table 49 (Bowditch) applying it at the top and the obs. alt. at the side, and take out the correction (always +) for the obs. alt. This is given for H. of E. 35 ft. Small table gives changes for other heights; add or subtract as table directs.

These corrections for dec. and alt. are used in *all* moon observations. With the corrected dec. and alt. proceed as in merid. alt. of sun.

Example: At sea, July 22, 1918. Obs. merid. alt. moon, lower limb, 59° 06′ 40″ N. Index error, + 2′. Height of eye, 25 ft. G. M. T., 11 h. 16 m. P.M.

Hor. parallax...	58′.4
Cor. Table 49...	39′ 24″
Cor. small table.	54″
Index error.....	+2′
Cor...........	+ 42′ 18″
Obs. alt........	59° 06′ 40″
T. C. A........	59° 48′ 58″ N.
	90° 00′ 00″
Z. D...........	30° 11′ 02″ S.
Dec...........	20° 01′ 18″ S.
Lat...........	50° 12′ 20″ S.

Dec. 10 P.M..	20° 10′ 18″ S.
Cor. 1¼ hr..	−9′
Cor. dec.....	20° 01′ 18″ S.
BY CONSTANT	
	+ 90° 00′ 00″
Dec.......	20° 01′ 18″
Cor........	− 42′ 18″
Const......	109° 19′ 00″
Obs. alt....	59° 06′ 40″
Lat........	50° 12′ 20″ S.

MERIDIAN ALTITUDE BELOW THE POLE

It is frequently possible to get an altitude of a star when it is crossing the meridian below the pole. The north pole of the heavens is marked very closely by the pole-star, which is never more than 1° 20′ distant from the pole. The stars in the northern part of the heavens apparently revolve around the pole, as may be plainly seen in the case of the constellation known as the "Dipper." When the given star is directly under the pole it is on the meridian, and will give the latitude just as correctly as when directly above it.

When in circumpolar regions where the sun does not set for six months, its merid. alt. below the pole can be taken.

The altitude of the pole is always equal to your lat. If the pole is directly over your head its altitude is 90°, which is your lat. If you go south 10°, the pole will lose 10° of alt., being now 80° high. From this fact we get our formula. If we know how far below the pole the observed body is, we can get the altitude of the pole by adding the alt. of the body to its distance from the pole, called *polar distance.* We find the polar distance by subtracting the declination from the distance, which is 90°, between the equator and the pole. Hence the formula P. D. + alt. = lat., or by the use of the constant:

$$+ 90° - \text{dec.} + \text{cor.} + \text{obs. alt.}$$

Example: Jan. 22, 1918. Obs. alt. *a* Ursa Majoris (*a* of the "Dipper") below pole, 8° 15′ N. H. of E., 10 ft. No index error.

	+	90° 00′ 00″
Dec.	−	62° 11′ 00″
Cor.	+ −	9′ 28″
Const.		27° 39′ 32″
Obs. alt.		8° 15′ 00″
Lat.		35° 54′ 32″

CONVERSION OF ARC TO TIME, AND VICE VERSA

Before proceeding further the student should learn how to convert longitude into time and time into longitude. .The former operation will enter into most of the calculations yet to come, and the latter is always part of longitude workings.

The conversion is based on the fact that the sun takes 24 hours to pass around the 360° of the earth's circumference. Divide 360 by 24 and you get the number of degrees he passes in one hour, *viz.*, 15°. Hence 15° of long. = 1 hour, and 1° = $\frac{1}{15}$ of 1 hour, or 4 minutes. Furthermore, 15′ of long. = 1 minute of time, and 1′ of long. = $\frac{1}{15}$ of 1 minute of time, or 4 seconds. Table 7, Bowditch, gives the various equalizations up to 360°, but you should be able to do without it.

To convert time into long.—Multiply the hours by 15 to get degrees. Divide the minutes by 4, and add the quotient to the number of degrees. If any minutes are left over, multiply them by 15. Divide the seconds by 4, and add the quotient to the minutes. Finally, multiply the remaining seconds by 15.

Example: Turn 4 hrs., 29 min., 38 sec. into long.

4	4)29(7°	4)38(9′
15	28	36
—	—	—
60	1 × 15 = 15′	2 × 15 = 30″
7	9′	
—	—	
67°	24′	

To convert long. into time.—Multiply each member of the quantity by 4 and divide by 60, adding any figures left over to the result on the right.

Example: Turn 50° 40′ 15″ into time.

50°	40′	15″
4	4	4
60)200(3 h.	60)160(2 m. + 20 m. = 22 m.	60)60(1 s. + 40 s. = 41 s.
180	120	60
20 m.	40 s.	00

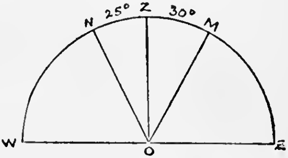
Ans. 3 hrs., 22 min., 41 sec.

It is from this convertibility of time into degrees and parts of degrees (and *vice versa*) that we get the expression hour-angle.

Hour-angle is the distance of a body east or west of the observer's meridian, expressed either in time or angle. Thus at 11 A.M. the sun's hour-angle is either 1 hour or 15° E.; at 1.15 P.M. it is either 1 hour and 15 min. or 18° 45′ W.

In other words, when the celestial body is east of you, its H. A. is the *time* it will take the revolving of the earth from west to east to bring the meridian on which you are under the meridian on which the body is, and the *distance* which your meridian travels in doing it is measured on the arc between the two meridians.

An observer at O (zenith Z) sees one star at N and another at M. The one at N has passed his zenith by 25°, or 1 h. 40 m., and its H. A. is west. The one at M has not yet reached his Z by 30°, or 2 h., and its H. A. is east.



The student must master these relations of time and arc. The conversion of one into the other is conveniently made by Table 7, Bowditch, which is readily understood.

When the longitude is known the H. A. can easily be computed. When the long. is unknown the H. A. must be found after an observation (explained under longitude). Since hour-angles are measured by the apparent movements of the celestial bodies, and not by the clock, they are measured by apparent time. Hence the rule for finding H. A. of sun, when long. is known. First find the loc l apparent time, thus: at the moment of observing the body note chronom. time. Turn your long. into time. If it is E. add it to the G. M. T. If W., subtract. Result is local mean time (L. M. T.). Apply the corrected equation of time. Result is local apparent time (L. A. T.).

In case the sun is the observed body, if the L. A. T. is more than 12 o'clock noon it is the H. A. west. If the local apparent time is before noon, subtract it from 12 hrs. and you have the H. A. east. That is, 2.30 P.M. is 2 h. 30 m. westerly H. A.; 10.30 A.M. is 1 h. 30 m. H. A. east.

LAT. BY EX-MERIDIAN ALT.

By using the H. A. of the sun we can get our lat. when the sun is not on the merid. It might be under a cloud then. But if we know our long., we can work ex-merid. alts. of the sun from 26 min. before noon to 26 min. after.

The process rests on the fact that near the merid. the alt. varies as the square of the interval from noon. The interval from noon is the H. A. Table 26, Bowditch, gives the change of alt. for 1 min., Table 27 these multiplied by squares of intervals.

Rule: Take chronom. time of obs. Correct for rate. Find the sun's H. A. as already explained. Enter Table 26 with the dec. of the sun at the top, and the lat. by D. R. at the side, and take out the change of alt. for 1 min. Enter Table 27 with the hour-angle at the top and the change of alt. at the side.

Pick out the corresponding reduction to the merid., selecting units and tenths separately and adding them. Add this to the T. C. A. to obtain the merid. alt. Subtract this from 90° to get Z. D., and apply the dec. to get the lat. as heretofore directed.

Example: At sea, July 11, 1918. Lat. by D. R. 50° 10′ 00″ N., long. 40° W. Obs. ex-merid. alt.. ⊙ 61° 45′ 30″. H. of E., 15 ft.; I. E., 4′ −. Chronom. time (corrected) 2 hrs., 38 min., 00 sec. P.M

G. M. T..	2 h. 38 m. 00 s. P.M.		
Long. W..	2 h. 40 m. 00 s.	Table 26, var. of alt...	2.5″
* L. M. T.	11 h. 58 m. 00 s. A.M.		
Equation.	− 5 m. 13 s.	Table 27 2″ =	1′ 45″
		Table 27 .5″ =	25″
L. A. T..	11 h. 52 m. 47 s. A.M.		
	12 h. 00 m. 00 s.	Cor. for alt...	2′ 10″
H. A....	7 m. 13 s. E.		

Obs. alt........................	61° 45′ 30″ S.
Cor. Table 46..................	+ 7′ 42″
T. C. A........................	61° 53′ 12″
	+ 2′ 10″
Merid. alt......................	61° 55′ 22″
	90° 00′ 00″
Z. D...........................	28° 04′ 38″ N.
Cor. Dec.......................	22° 10′ 36″ N.
Lat............................	50° 15′ 14″ N.

*In this case we have to add 12 hrs. to G. M. T. in order to subtract long.

In this working the merid. alt. obtained is that for the merid. on which the ship is at the time of observation. The *noon* lat.

must be computed by D. R., according to the course and dist. to noon. In the above example, if the ship were running at 12 knots per hour, N. 40° E., she would in 7 min. 13 sec. make 1.65 miles and her diff. lat. would be about 1.3′.

SIDEREAL TIME AND RIGHT ASCENSION

Astronomical time is reckoned from noon of one day to noon of the next, and hence the astronomical day corresponds to the 24 hours of a ship's run. The hours are counted from 1 to 24, so that 4 o'clock in the morning of Oct. 5 is astronomically 16 o'clock of Oct. 4.

Right ascension is practically celestial longitude. A place on the earth is located by its latitude and longitude; a heavenly body by its declination and right ascension. But R. A., as it is indicated, is not measured in degrees and minutes, nor is it measured east and west. It is reckoned in hours and minutes all the way around the sky from west to east through 24 hours.

The celestial meridian from which this celestial longitude begins is not that of Greenwich, but is that passing through the equator at the point where the sun crosses the line in the spring.

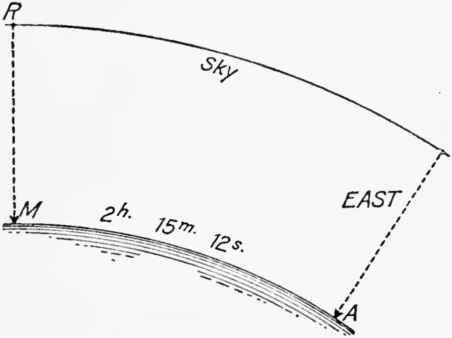
When we speak of a star as having a R. A. of 3 hrs., 42 min., 15 sec., we mean that any given spot on the surface of the earth will occupy 3 hrs., 42 min., 15 sec. in revolving from the prime meridian of celestial long. to the meridian of the star.

You will meet with the expression right ascension of the meridian. That means the R. A. of the meridian on which you are, and in many stellar observations you need to know it in order to compare it with the R. A. of the star.

It so happens that the R. A. of the meridian and local sidereal time are the same thing. Sidereal time is "star" time, as opposed to solar or "sun" time. The sidereal day contains 24 hours, and begins when the prime celestial meridian (at which celestial longitude—or R. A.—begins) is right over the meridian on which you are. It is then what may be called sidereal noon at your position, just as it is solar noon when the sun is on the meridian.

Refer to the diagram and suppose R to be the prime celestial meridian, and M your meridian. When M is under R sidereal time at M begins. Also right ascension is measured eastward in hours and minutes from R. Now if M occupies 2 hrs., 15 min., 12 sec. in revolving with the motion of the earth to A, when it arrives at A it will be 2 hrs., 15 min., 12 sec. o'clock sidereal time at M. And that must also be the R. A. of the meridian (M.) because R. A. is measured from the same point as sidereal time.

The student must now learn two things: first, how to find the sidereal time at Greenwich corresponding to any given hour of mean time there, and secondly, how to find the sidereal time corresponding to any given hour at his own meridian. It is obvious that if you can find the former, you can easily get



the latter by applying the longitude of your meridian (converted into time).

A sidereal day measures in mean time—that is, by a chronometer or ordinary clock—23 hrs., 56 min., 04 sec. In other words, every hour, minute, and second in a sidereal day is a little shorter than its counterpart in a solar day. So, in turning mean time into sidereal time, we have to make some allowances. Table 8, Bowditch, gives the allowances for changing sidereal to mean time, and Table 9 for changing mean to sidereal. Similar tables are to be found in the N. A.

The N. A. will give you the sidereal time at Greenwich noon for every day in the year (right ascension of mean sun, pages 2 and 3). Right ascension of the mean sun is the sidereal time at Greenwich when the mean time clock shows noon. Convert G. M. T. into Greenwich sidereal time (G. S. T.) thus:

Add to G. M. T. the G. S. T. for the preceding noon, and the allowances given in Table 9, for the number of hours, minutes, and seconds in the G. M. T. If the sum is more than 24 hours, subtract 24 hours from it, because at the end of 24 hours Sid. T. begins over again.

Example: Required G. S. T., Nov. 2, 1918, when the G. M. T. by chronom. (corrected) was 7 hrs., 25 min., 15 sec. P.M.

G. M. T.	7 h. 25 m. 15 s.
Sid. T. at G. at preceding noon	14 h. 43 m. 47.7 s.
From table 7 hrs. 25 m.*	1 m. 13 s.
Sid. T. at G.	22 h. 10 m. 15 s.

* The 15 sec. of G. M. T. are disregarded because the allowance is only .041″.

To find local sidereal time (L. S. T.), which is also R. A. M., simply apply your long. (in time) to the G. S. T.

Example: Required sidereal time at ship Aug. 19, 1918, when G. M. T. was 11 hrs., 15 min., 20 sec. P.M. Long. 60° 15′ W.

G. M. T.	11 h.	15 m.	20 s.
G. S. T. preceding noon.	9 h.	48 m.	06.2 s.
Allowance 11 h. 15 m.		1 m.	50.8 s.
G. S. T.	21 h.	05 m.	17 s.
Long. W.	4 h.	01 m.	00 s.
L. S. T. (or R. A. M.)	17 h.	4 m.	17 s.

LATITUDE BY THE POLE-STAR

The pole-star (Polaris) is 1° 20′ distant from the North Pole. It apparently revolves around the pole, as other circumpolar stars do. As already explained, the altitude of the pole equals your lat. When Polaris is due E. or W. of the pole its alt. is your lat. When it is on the meridian above the pole, your lat. = alt. − 1° 20′. At its lower transit, lat. = alt. + 1° 20′.

The R. A. of M. advances from 0 to 24 hours in exactly the same time that Polaris appears to revolve around the pole, and the astronomers have made a table by which, providing we know the R. A. of M., we can make the addition or subtraction to the star's alt. at any hour. Hence the rule:

Take the alt. and note chronom. time. Correct both as usual. Find the local sidereal time (which is also R. A. of M.) as already explained. With the local sidereal time enter Table I., in the back part of the N. A., applying the hours at the top of the column and the minutes at the side. You will thus obtain a correction which, according to sign prefixed to it, is to be applied to the obs. alt. of Polaris. The result will be the approximate latitude. The problem is not regarded as giving a latitude as exact as that obtained from a star's meridian passage.

Example: At sea, Dec. 20, 1918. Long. 45° 15′ W.; obs. alt. of Polaris, 40° 27′ 00″; no I. E.; H. of E., 20 ft.; G. M. T., 11 hrs., 30 min., 00 sec. P.M.

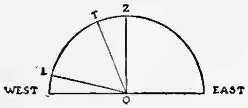
G. M. T.	11 h. 30 m. 00 s. P.M.
S. T. noon	17 h. 53 m. 02.4 s.
Allowance 11½ h.	1 m. 53.3 s.
	29 h. 24 m. 55.7 s.
	24
G. S. T.	5 h. 24 m. 55.7 s.
Long. W	3 h. 01 m. 00 s.
L. S. T.	2 h. 23 m. 55.7 s.
Obs. alt.	40° 27′ 00″
Table 46	− 5′ 31″
T. C. A.	40° 21′ 29″
Correction	−1° 05′ 48″
Lat.	39° 15′ 41″ N.

TIME AZIMUTHS

Under the head of Deviation the student was told how to get the dev. by an azimuth of the sun. We now see that the L. A. T. needed in consulting the azimuth tables is obtained by getting the G. M. T. of the obs., applying our long. to it to find L. M. T., and converting that into L. A. T. with the equation.

To take an azimuth by moon, star, or planet, we need the H. A. of the body. This is always the diff. between the R. A. M. and the R. A. of the observed body, which should be made clear by the following diagrams. These express all the relations of H. A. and R. A. The semicircle denotes the arch of the sky from horizon to horizon.

H. A. West

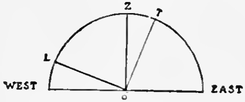


O = Observer.
Z = Meridian of observer.
L = Prime meridian of celestial long.
T = Star.
LT = R. A. of star.
LZ = R. A. of meridian.
TZ = H. A. of star.

The H. A. being west, the formulæ are:

LT = LZ − TZ	(R. A. star = R. A. M. − H. A. star)
LZ = LT + TZ	(R. A. M = R. A. star + H. A. star)
TZ = LZ − LT	(H. A. star = R. A. M. − R. A. star)

H. A. East



The H. A. being east, the formulæ:

LT = LZ + TZ	(R. A. star = R. A. M. + H. A. star)
LZ = LT − TZ	(R. A. M. = R. A. star − H. A. star)
TZ = LT − LZ	(H. A. star = R. A. star − R. A. M.)

Hence, to find a star's H. A. find the L. S. T., which is your R. A. M. Get the star's R. A. from the N. A. Subtract the less R. A. from the greater. If the star's R. A. is greater the H. A. is east, and *vice versa,* as above shown.

To get the true azimuth enter the table with this H. A., but in case of moon, star, or planet, always apply the H. A. in the P.M. part. If the star's dec. is larger than those in azimuth tables, take its alt. and use Table V., H. O. Book, 200.

LONGITUDE BY TIME SIGHT OF SUN

The standard method of ascertaining longitude by observation is by a chronometer or time sight.

Since the earth revolves (apparently) around the earth once in 24 hours, passing through 15° of long. every hour, if we can ascertain how many hours and minutes east or west of Greenwich the sun is, and how many hours and minutes east or west of the sun we are, we shall know our long. When the long. is not known, then the problem is to find the local H. A. of the sun.

The H. A. from Greenwich we carry with us in the shape of the chronom., which tells us G. M. T., and that, of course, is simply the H. A. of the sun there. If we find the H. A. here—at our meridian—the difference between the two will be the number of hours, minutes, and seconds we are east or west of the Greenwich meridian, and this quantity is, as we have seen, convertible into the degrees, minutes, and seconds of longitude.

The computation of the H. A. of the sun is a problem in spherical trigonometry; but the navigator has only to know how to use the tables prepared by the astronomers and to employ simple arithmetic. The necessary data are the T. C. A., the polar distance (P. D.) and the lat. At the instant of getting the altitude with the sextant note the chronom. time accurately and make the usual correction. Correct the dec. and equation of time according to G. M. T. Convert G. M. T. into G. A. T. by applying the equation as directed by the N. A. You need G. App. T. because from your observation of the sun you get L. App. T. If you prefer, you can wait till you have computed that, and then convert it into L. M. T. so as to compare it with G. M. T.

If you are in N. lat. and the dec. is N., or in S. lat. and the dec. is S., subtract the corrected dec. from 90° to get the polar distance. If you are in N. lat. and dec. is S., or in S. lat. and dec. is N., add dec. to 90° to get P. D. The rule for the rest of the operation is this:

Add together the P. D., the lat., and the T. C. A. Divide the sum by 2, and call the

G. M. T.	10 h. 09 m. 39 s. A.M.	Dec.	9° 51 .1′ S.
Sid. time preceding noon	47 m. 58 s.	Cor.	− 9 .2′
Allowance	3 m. 38 s.	Cor. dec.	9° 42′ S.
G. S. T. (April 4)	23 h. 01 m. 15 s.		90°
		P. D.	99° 42′

R. A. ✳	22 h. 01 m. 04 s.
Cor.	+ 3 m. 05 s.
R. A. ✳	22 h. 04 m. 09 s.

Obs. alt.	16° 01′ 00″		
I. E.	+ 5′		
	16° 06′ 00″		
Cor. Table 46	− 9′ 57″		
T. C. A.	15° 56′ 03″		
P. D.	99° 42′ 00″	cosec.	.00625
Lat.	37° 09′ 00″	sec.	.09851
	2) 152° 47′ 03″		
½ s.	76° 29′ 00″	cos.	9 .36871
Diff.	60° 33′ 00″	sin.	9 .93991
		Haversine	9 .41338

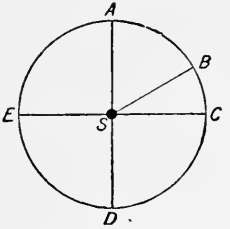
H. A.	4 h. 04 m. 46 s. E
✳ R. A.	22 h. 04 m. 09 s.
R. A. M. or L. S. T.	17 h. 59 m. 23 s.
G. S. T.	23 h. 01 m. 15 s.
Long.	5 h. 01 m. 42 s. = 75° 28′ W.

Lat. 37° 09′ N. Venus E. of merid. Obs. alt. 16° 01′. Index error, + 5′. Height of eye, 45 ft. (This sight was actually taken at sea on the given date.) (See table, page 107).

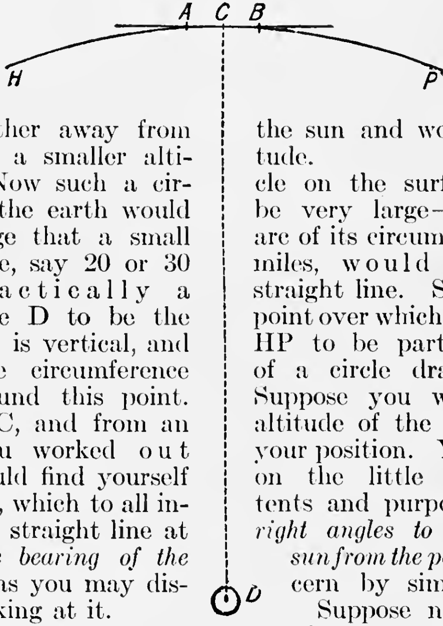
SUMNER'S METHOD

We now come to the method which, in its latest development, promises to supersede all the older ones. Sumner's method, called after the American seaman who discovered its principle, rests upon certain fundamental truths of navigation.

Wherever the sun is, it must be perpendicularly above some spot on the surface of the earth. Suppose the sun to be immediately above the center of the circle, S. Then



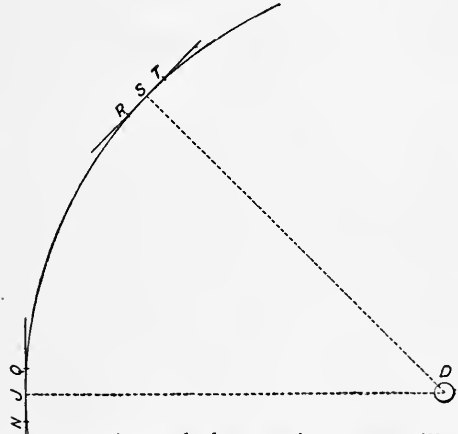
if a man at A takes an altitude, he will get precisely the same one as men at B, C, D, and E, because they are all at equal distances from the sun, and hence on the circumference of a circle whose center is S. Conversely, if several observers situated at different parts of the earth's surface take simultaneous altitudes, and these altitudes are all the same, then these observers must all be on the circumference of a circle, and *only one* circle. If you moved one observer to the circumference of a larger circle, for instance, he would be



farther away from the sun and would get a smaller altitude.

Now such a circle on the surface of the earth would be very large—so large that a small arc of its circumference, say 20 or 30 miles, would be practically a straight line. Suppose D to be the point over which the sun is vertical, and HP to be part of the circumference of a circle drawn around this point. Suppose you were at C, and from an altitude of the sun you worked out your position. You would find yourself on the little arc AB, which to all intents and purposes is a straight line at *right angles to the true bearing of the sun from the point* C, as you may discern by simply looking at it. Suppose now we continue the circle around D. Place an observer at J, and let him take an altitude of the sun. He will be on the circumference of the same circle, but on the small arc QN, which is again practically a straight line and at right angles to the true bearing of the sun. At S. he would find himself on the arc RT—again a small straight line at right angles to the bearing of the sun.

If you draw any other circle, and mark



points of observation, you will get similar results.

Hence: Any person taking an altitude of a celestial body must be, for all practical purposes, on a straight line which is at right angles to the true bearing of the body observed.

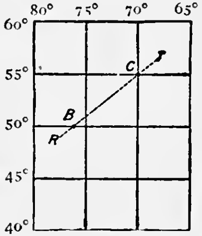
Such a line is called a Sumner line, or a line of position.

It must now be perfectly clear to the

student that if the sun bears due north or south of the observer, the resulting line of position *must* run east and west; or, in other words, it is a parallel of lat. And that explains why a meridian observation gives the most accurate lat.

Again, if the sun bears due east or west the resulting line of position *must* run north and south; or, in other words, it is a meridian of longitude. And that explains why a prime vertical observation gives the most accurate longitude. The observer at J might be well over toward Q or N—in other words, mistaken considerably as to his latitude—but he would get his longitude all right.

But in the case of the man at S, the longitude cannot be known exactly unless the lat. is. Transfer the line to a chart. We know that we are somewhere on that line RT. If the latitude is 50° N., we must be at the point where the line crosses the 50th parallel, which is at B. If the lat. is 55°, we must be at C. This shows how necessary the lat. is in cases where the observed body does not bear east or west. On the other hand, if you wished to get your lat. from the line RT, you would have to know your long.



accurately. If the long. was 70° W., you would know you were at C, lat. 55°.

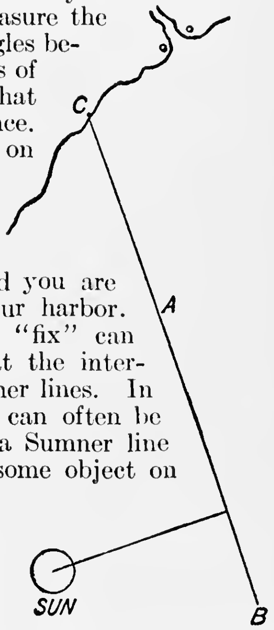
Hence we get this operation from a single Sumner line: Whenever you take a chronometer sight of the sun, or any other heavenly body, from the L. A. T. or the H. A. obtained in the computation get the true bearing of the body from the azimuth tables. Then, through the position obtained, draw a Sumner line running at right angles to the true bearing.

You are absolutely sure to be somewhere on that line at the instant of observation; you cannot possibly be on any other.

Here are some uses of the single Sumner line. Suppose you are standing in N.W. toward land, and your position is not quite certain. You take a chronom. sight and get a position from which the sun bears S. 76° W. (256°). You draw the Sumner line AB at right angles to it, running N. 14° W. (346°). The line, if continued, will reach land at C, and if you sail on it you will make that point.

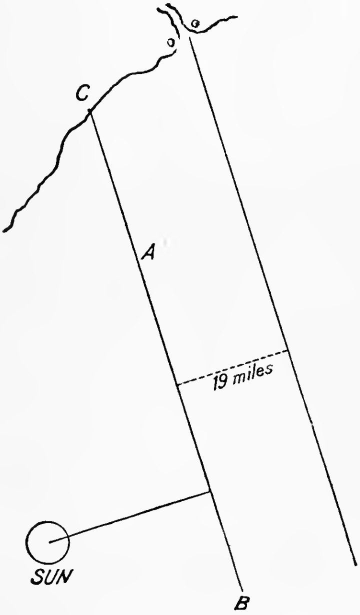
Suppose that at C there stood a well-known lighthouse, whose light was visible 18 miles at sea in clear weather. When that light popped into view over the horizon, you could at once verify your position by taking its bearing, and then sail in with boldness—not forgetting to use the lead.

But suppose you do not wish to make the point C, which is at the end of your Sumner line. Some 20 miles farther up the coast is a well-lighted harbor, and you wish to make that. All you have to do is to draw a second line of bearing, parallel to the first and ending at the point you wish to make. Measure the distance at right angles between your two lines of bearing. Sail over that course and distance. You will then be on the second line of bearing, when you at once take the course 346° true, of the first line, and you are bound to make your harbor.



But an accurate "fix" can be obtained only at the intersection of the Sumner lines. In coastwise work this can often be found by crossing a Sumner line with a bearing of some object on shore, say a high mountain.

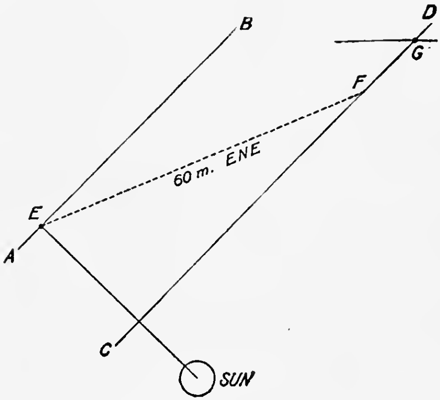
At sea the simplest form is the crossing of a Sumner line obtained from a long. sight with one obtained by merid. sight, which is a parallel of lat. Suppose that an observation at 8 A.M. gives you a Sumner line AB, at right angles to the sun's bearing. From 8 A.M. to noon you



make 60 miles E.N.E. From the A.M. position at E lay off the course and distance, and at the end of this draw the line CD, parallel to the Sumner line, AB. The point

G, at which your noon parallel of lat. cuts CD, will be your noon position.

The old established way of making a noon position is this: Take your morning sight for long., but do not work it out. Take your noon sight for lat., and then by D. R. compute backward to the correct lat. at the



time of the morning sight, and with this lat. work out the longitude. Then carry the longitude up to noon by D. R., and thus establish the lat. and long. at noon.

The method by a Sumner line and a parallel is far shorter and quite as accurate. By it you have found that you are on small arcs of two different circles at the same time.

You can be *only* at their point of intersection. And that is the whole theory of the Sumner method.

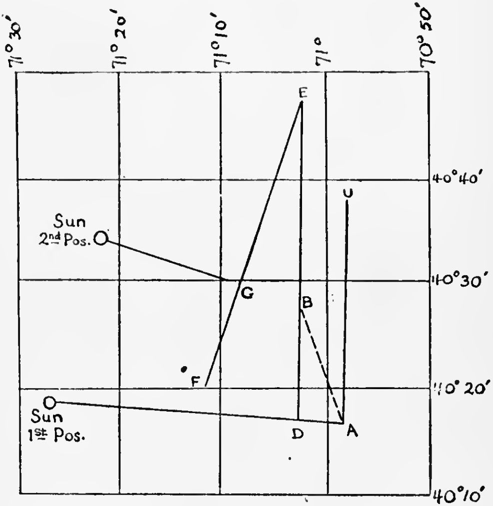
To find two intersecting Sumner lines, neither of which is a parallel of lat., you may use successive observations of the same body, or simultaneous observations of two bodies. Supposing the ship to be stationary, take two observations of sun, letting the bearing change at least 2 points. Sumner lines drawn from these observations will cross at an angle of 2 points and you must be at the intersection.

But the ship is almost always going and you proceed as in the work with a Sumner line and the noon parallel.

Having taken your first sight and drawn your Sumner line, from *any* point on this line, lay off the course and distance made up to the time of taking the second sight and drawing the second Sumner line. At the extremity of the course-line draw a third line parallel to the first Sumner line, and prolong it till it cuts the second Sumner line. The intersection of this parallel with the second Sumner line will be the position of the ship at the time of the second observation.

Refer to the last previous diagram. If you had been at the point G when you took your morning sight and had been ignorant of your lat., you would at any rate have got the Sumner line CD at right angles to the sun's bearing at that time and would have been somewhere on that line. If you had remained at anchor till noon, you would have found your lat. and your position G. This explains why the carrying forward of a Sumner line till another is obtained to intersect it, gives a true position.

(See example at top of page 118.)



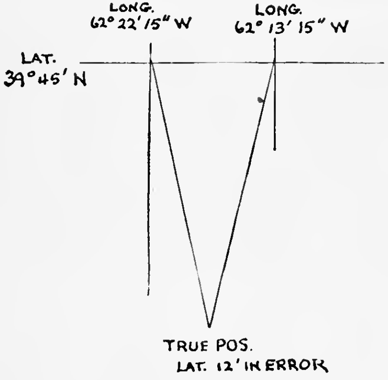
A—Ship's 1st position.
G—Ship's 2d position.
A B—Course between sights.
A C—1st Sumner line.
D E—1st Sumner line carried forward.
F E—2d Sumner line.
E is the intersection of D E and F E and the correct pos. of ship.
Lat............ 40° 48′ N.
Long........... 71° 02′ W.
Lat. by D. R. was 20 m. too far S.

Example: At sea, June 1, 1918. Obs. alt. ⊙ 33° 50′ 00″; G. M. T., 8 hrs., 55 min., 00 sec. P.M.; H. of E., 20 ft.; no I. E.; lat., 40° 17′ N. (See tables, pages 119, 120.)

Tw hours later took another sight, which gave a corrected alt. of 11° 15′. G. M. T., 10 hrs., 58 min. Ship in the meantime made 12 miles, N. 20° W. (See diagram page 117.)

In practice the first sight would give a correct long. despite the lat. error, because the sun is on the P. V.

Example: Sumner lines by simultaneous obs. of two stars, one east and one west. Jan. 25, 1918. Obs. alt. Procyon 32° 44′ E., and Hamal 58° 21′ W. Lat. by D. R., 39° 45′ N. H. of E. 20 ft. No I. E. G. M. T. first obs., 12 hrs., 01 min., 00 sec.; second obs.,



G. M. T.	8 h. 55 m. 00 s. P.M.
Cor. equat.	+ 2 m. 26 s.
G. A. T.	8 h. 57 m. 26 s. P.M.

Cor. dec.	22° 02′ 06″ N.
	90° 00′ 00″
P. D.	67° 57′ 54″

Course 340°, dist. 12 miles.

Diff. lat.	11.3′
Lat. 1st obs.	40° 17′ 00″ N.
	+11′ 18″ N.
Lat. 2d obs.	40° 28′ 18″ N.

Obs. alt.	33° 50′ 00″		
Table 46	+10′ 19″		
T. C. A.	34° 00′ 19″		
P. D.	67° 57′ 54″	cosec.	.03294
Lat.	40° 17′ 00″	sec.	.11756
	2)142° 15′ 13″		
½ s.	71° 07′ 36″	cos.	9.50984
Diff.	37° 07′ 17″	sin.	9.78068

Hav.	9.44102 =	4 h. 13 m. 34 s. L. A. T.
		8 h. 57 m. 26 s. G. A. T.
Long. 70° 58′ 00″ W.	=	4 h. 43 m. 52 s.

Azimuth N. 89° W.
Sumner line N. 1° E.
(Sun practically in the prime vertical.)

G. M. T..... 10 h. 58 m. 00 s. P.M.
Cor. equat... + 2 m. 25.6 s.
G. A. T...... 11 h. 00 m. 25.6 s.

Cor. dec....... 22° 02′ 42″ N.
90° 00′ 00″
P. D.......... 67° 57′ 18″

P. D.........	67° 57′ 18″	cosec......	.03299
Lat..........	40° 28′ 18″	sec........	.11874
T. C. A.......	11° 15′ 00″		
	2)119° 40′ 36″		
½ s.........	59° 50′ 18″	cos........	9.70115
Diff..........	48° 35′ 18″	sin........	9.87501

Hav...... 9.72789 = 6 h. 15 m. 48 s. L. A. T.
11 h. 00 m. 26 s. G. A. T.

Long. 71° 09′ 30″ W. = 4 h. 44 m. 38 s.

Azimuth N. 71° W.
Sumner line N. 19° E. (or S. 19° W.)

12 hrs., 02 min., 10 sec. (See tables, pages 122, 123.)

It should be obvious to the student who has mastered the subject up to this point that all observations of celestial bodies give Sumner lines of position.

For this reason the navigator should accustom himself to view all his operations as applications of the fundamental principles of the Sumner method, and accordingly draw a Sumner line at right angles to the true bearing, as obtained from the azimuth tables for the local time of the observation, the lat. of ship and dec. of observed body. In fact, the practice of navigation (in the navy, at any rate) now makes the Sumner method its fundamental one, and treats all else as auxiliary.

Comparison with the compass bearing shows the error of the compass at the time of the observation, and the deviation on the course is readily ascertained.

The patent log should be read at the time of observation, in order that the course and distance made good between that and the next observation may be computed. This is essential to the carrying forward of a line of position, as previously described.

G. M. T.	12 h. 01 m. 00 s.
Sid. time noon.	20 h. 15 m. 55.8 s.
Allowance 12 hr.	1 m. 58.3 s.
	32 h. 18 m. 54.1 s.
	24 h.
G. S. T.	8 h. 18 m. 54.1 s.

Dec. Procyon.	5° 26′ 00″ N.
	90° 00′ 00″
P. D.	84° 34′ 00″

Obs. alt.	32° 44′ 00″		
Cor.	– 5′ 56″		
T. C. A.	32° 38′ 04″		
P. D.	84° 34′ 00″	cosec.	.00196
Lat.	39° 45′ 00″	sec.	.11416
	2)156° 57′ 04″		
½ s.	78° 28′ 32″	cos.	9.30060
Diff.	45° 50′ 28″	sin.	9.85576

Hav.	9.27248 =	3 h. 25 m. 02 s. H. A. East
		7 h. 35 m. 03 s. R. A. ✻
		4 h. 10 m. 01 s. L. Sid. T.
		8 h. 18 m. 54 s. G. Sid. T.
Long. 62° 13′ 15″ W. =		4 h. 08 m. 53 s.

True bearing N. 113° E.
Sumner line S. 13° W.

G. M. T........	12 h. 02 m. 10 s.
Sid. time noon .	20 h. 15 m. 55.8 s.
Allowance 12 h.	1 m. 58.1 s.
	32 h. 20 m. 03.9 s.
	24 h.
G. S. T.........	8 h. 20 m. 03.9 s.

Dec. a Arietis..	23° 04′ 42″ N.
	90°
P. D..........	66° 55′ 18″

Obs. alt......	58° 21′ 00″
Cor..........	− 4′ 59″
T. C. A.......	58° 16′ 01″
P. D..........	66° 55′ 18″
Lat..........	39° 45′ 00″
	2)164° 56′ 19″
½ s..........	82° 28′ 09″
Diff..........	24° 12′ 08″

cosec.....	.03624	
sec........	.11416	
cos........	9.11761	
sin........	9.61270	
Hav......	8.88071 =	2 h. 08 m. 00 s. H. A. West
		2 h. 02 m. 34.5 s. R. A. ✳
		4 h. 10 m. 34.5 s. L. S. T.
		8 h. 20 m. 03.9 s. G. S. T.
Long. 62° 22′ 15″ W. =		4 h. 09 m. 29.4 s.

True bearing N. 112° W.
Sumner line S. 12° E.
(See diagram page 118.)

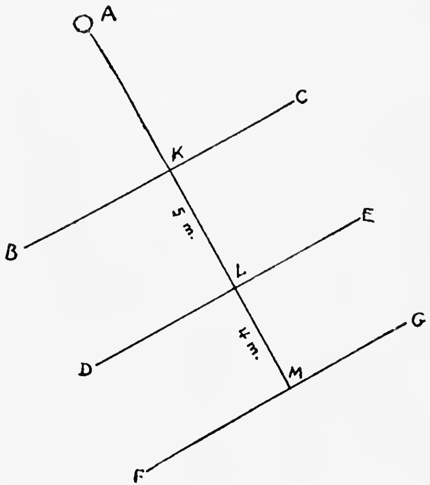
THE ST. HILAIRE METHOD

This method, as now applied to the Sumner system, bids fair to reduce astronomical navigation to a single formula. The principle upon which it rests is this. At any lat. and long. the altitude and azimuth of a celestial body can be calculated and a Sumner line drawn accordingly. The position may be *assumed* and the calculation made from it. Then the actual altitude of the celestial body can be compared with the calculated one. The difference between the two will determine the correct place of the Sumner line.

The position by D. R. may be used as the assumed one, or one may be taken in its neighborhood. The observed alt. will be higher or lower than the calculated one. If higher, you are nearer the sun than you assumed; if lower, you are further from it. The distance by which the observed and assumed positions disagree is equal to the difference between the two altitudes and is called the alt. diff., or intercept.

The difference, expressed in minutes, is laid off on the line of the body's true bearing in minutes of sea distance, or nautical miles, and the assumed Sumner line is moved that distance toward or from the body. For it should be clear to the student that the line of the object's bearing is an arc of a great circle passing around the circumference of the earth, and therefore its minutes are nautical miles.

It cannot matter whether the assumed position is too near the observed body or



too far away. The alt. of the observation will correct the error and give what is called the "position point," and through this the correct line of position is drawn.

If A be the observed body and AM the line of its true bearing, you may assume that you are somewhere on BC or FG. If the true alt. locates you on the line DE, you are 5 miles further from the body than you supposed when you assumed the line BC, or 4 miles nearer than you assumed on FG.

Hydrographic Office publication No. 200 contains all the tables needed for this method. From one you can get your assumed alt. and from another your azimuth. The manner of obtaining the calculated alt. from the table is fully explained in the book and is too long for reproduction here. Moreover, the practice of most navigators is to make their own calculation. The process is simple and quick and it eliminates the errors to which the interpolations required in using the table render the work liable.

There are three formulæ for calculating the alt., but the most satisfactory is the cosine-haversine formula. This requires the use of Table 44, Bowditch, to find the cosine, and Table 45, Bowditch,* to find the logarithmic and natural haversines. The last named stand in the columns abreast of the log. haversines. Compute what the L. A. T. will be at the moment of taking obs., and take obs. at that time. Also compute lat. and dec. for that time. Or assume a lat. and long. near those by D. R. and compute L. A. T. and dec. accordingly. Then proceed as follows:

Add the log. haversine of the L. A. T. or

* Unless you use H. O. Book 200.

H. A., log. cosine lat. and log. cosine dec. Sum is log. haversine of an arc used only to obtain the corresponding natural haversine. Call the arc M. If lat. and dec. are of same name, find diff. and take out its natural hav. If lat. and dec. have different names, add them and take out nat. hav.

Add nat. hav. M. and nat. hav. of sum or diff. of lat. and dec. This gives nat. hav. of the calculated zenith dist., which take out. 90° − Z. D. = calculated alt.

The difference between the calculated alt. and the obs. alt. is the alt. diff. or intercept. Obs. alt. larger, you are nearer obs. body than your assumed position, and *vice versa.*

Lay off the alt. diff. along the line of the obs. body's true bearing, toward or from it as the case requires. You can plot this if your chart permits, but it is usually better to compute the new position point, and draw the correct Sumner line through it. To do this regard the true bearing of observed body as a course and alt. diff. as a dist. With these enter the traverse tables and get diff. lat. and dep. By mid. lat. get the diff. long. Apply diff. lat. and diff. long. to the assumed position point and obtain those of correct point.

In selecting the log. hav. of L. A. T. it is quicker to reckon in astronomical time, thus: 22 hrs., 30 min. L. A. T., Jan. 21, rather than 1 hr., 30 min. H. A. east on Jan. 22.

Example: At sea, Jan. 15, 1918. Lat. by D. R. 30° 10′ N., long. 45° 15′ W. T. C. A., ⊙ 17° 41′ 00″. Sun bearing S. and E. L. A. T., 8 hrs., 28 min., 56 sec. A.M. Required, alt. diff. and azimuth to lay off line of position.

(For convenience ascertainment of L. A. T. and correction of alt. are omitted. L. A. T. can be reckoned as 20 hrs., 28 min., 56 sec. ast. time.)

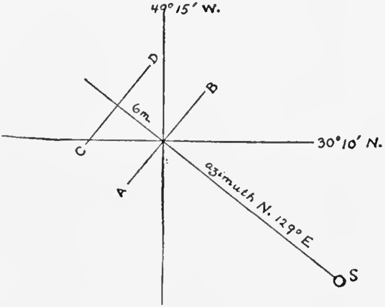
L. A. T.	20 h. 28 m. 56 s.	Log. hav.	9.29550
Lat.	30° 10′ 00″ N.	Log. cos.	9.93680
Dec.	21° 14′ 54″ S.	Log. cos.	9.96942
		Log. hav. M.	9.20172
		Nat. hav. M.	.15911
L. + D.	51° 24′ 54″	Nat. hav.	.18817
Calc. Z. D.	72° 13′	Nat. hav.	.34728
	90° 00′		
Calc. alt.	17° 47′		
Obs. alt.	17° 41′		
Alt. diff.	6′	Azimuth, N. 129° E.	

To find the lat. and long. of the correct position point, reverse sun's bearing. Then:

Course	Dist.	Diff. Lat.	Dep.	Diff. Long.
N. 51° W. or 309°	6	3.8	4.7	5′

Lat.	30° 10′ N.	Long.	45° 15′ W.
Diff. lat.	3′ 48″ N.	Diff. long.	5′ W.
New lat.	30° 13′ 48″ N.	New long.	45° 20′ W.

Or for practical purposes, lat. 30° 14′ N., long. 45° 20′ W. Mark this point on chart and through it draw correct line parallel to

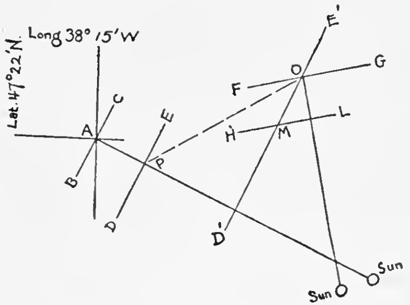


A B, assumed line of position drawn through lat. 30° 10′ N., long. 45° 15′ W.
C D, correct line of position 6 miles away from S, the Sun, because obs. alt. is smaller than calc. alt.

assumed line as in above diagram. Where simultaneous sights of stars are taken the same method applies. Where successive sights with intervening run are used, bring forward the first correct position line to the second one, as shown in diagram on page 130.

ST. HILAIRE MERIDIAN FORMULA

As you approach close to the meridian the cosine-haversine formula becomes uncertain, because the hour-angle is so small. The author has used it with H. A. of 6 minutes with good results. On the meridian it cannot be used, because the H. A. is zero. But the St. Hilaire method of a calculated alt. is nevertheless available. You may compute the zenith distance by the formula P. D. − co.-lat. = Z. D., as illustrated in the example on page 131, kindly sent to the author by the Hydrographic Office. It will be noted that two erroneous lats. are assumed, one north and one south of the correct one.



A—Assumed position of ship at first sight.
B C—Sumner line 1st assumed pos.
D E—Corrected 1st Sumner line.
P O—Ship's course between sights.
F G—Sumner line at second pos. by D. R.
H L—Corrected 2d Sumner line.
D′ E′—Parallel to 1st corrected Sumner line, brought forward to cut corrected second time.
M—Intersection of H L and D′ E′, ship's correct position at time of second sight, showing that assumed position on first line, B C, was too far north.

At sea, April 21, 1917, in lat. by dead-reckoning either 50° 20′ N., long. 20° 20′ W., or lat. 50° 10′ N., long. 20° 20′ W., the true meridian alt. was 51° 30′, sun bearing south; find the intercept and lat.

L. A. T.	0 h. 0 m. 0 s.	Alt.	51° 30′
Long.	1 h. 21 m. 20 s.	Z. D.	38° 30′
G. A. T.	1 h. 21 m. 20 s.	Dec.	11° 45.5′ N.
Equation	− 1 m. 15 s.	Cor.	+ 1.1′
G. M. T.	1 h. 20 m. 05 s.	Dec.	11° 46.6′ N.
		P. D.	78° 13.4
Co-Lat.	39° 40′	Co-Lat.	39° 50′
P. D.	78° 13.4′	P. D.	78° 13.4′
Calc. Z. D.	38° 33.4′	Calc. Z. D.	38° 23.4′
True Z. D.	38° 30.0′	True Z. D.	38° 30.0′
Alt. diff.	3.4′ S.		6.6′ N.
Lat. D. R.	50° 20′ N.	Lat.	50° 10′ N.
Alt. diff.	3.4′ S.	Alt. diff.	6.6′ N.
True lat.	50° 16.6′ N.	True lat.	50° 16.6′ N.

The author has proposed a formula, which seems to him to be more convenient. This formula has been submitted to the Hydrographic Office and pronounced correct.

Compute the meridian altitude, just as you do when ascertaining the alt. correction for a noon constant. Apply the alt. cor. to the computed alt. to get the correct calc. alt. Compare the obs. alt. with it and obtain the alt. diff. Apply this to the lat. assumed (or lat. by D. R.), making it nearer or further from the sun as the alt. diff. indicates, and you will have the correct lat.

Example: At sea, June 15, 1918. Obs. merid. alt. Sun, 71° 15′ 00″ S. Index error, − 3′. H. of E., 25 ft. G. M. T., 3 hrs., 01 min., 15 sec. P.M.

Old Way		St. Hilaire	
Obs. alt.	71° 15′ 00″	Lat. by D. R.	41° 50′ 00″ N.
Cor.	+ 7′ 48″		90° 00′ 00″
T. C. A.	71° 22′ 48″	Co-lat.	48° 10′ 00″ N.
	90° 00′ 00″	Cor. dec.	23° 18′ 00″ N.
Z. D.	18° 37′ 12″ N.	Calc. alt.	71° 28′ 00″
Cor. dec.	23° 18′ 00″ N.	Cor. Table 46.	− 7′ 48″
Lat.	41° 55′ 12″ N.	Cor. calc. alt.	71° 20′ 12″
		Obs. alt.	71° 15′ 00″
		Alt. diff.	5′ 12″
		Lat. by D. R.	41° 50′ 00″
		Cor. lat.	41° 55′ 12″ N.

It is important to remember to apply the alt. correction to the computed alt. Otherwise you would have to apply it to the obs. alt. and so lose time. This operation is preparing a constant, and if you transfer the correction from the obs. alt. to the constant, you *must change the sign.* All the work, except finding the alt. diff. and applying it to the assumed lat., is done *before* taking the observation.

Example: Mar. 15, 1918. Obs. merid. alt. Aldebaran, 71° 21′ 00″ S. No index error. H. of E., 20 ft.

Old Way		St. Hilaire	
Obs. alt.✳...	75° 21′ 00″ S.	Lat. by D. R...	30° 55′ 00″ N.
Correction..	− 4′ 39″		90° 00′ 00″
T. C. A.....	75° 16′ 21″	Co-lat........	59° 05′ 00″
	90°	Dec...........	16° 20′ 48″
Z. D........	14° 43′ 39″ N.	Calc. alt.......	75° 25′ 48″ S.
Dec........	16° 20′ 48″ N.	Correction.....	+ 4′ 39″
Lat.........	31° 04′ 27″ N.	Cor. calc. alt...	75° 30′ 27″ S.
		Obs. alt........	75° 21′ 00″ S.
		Alt. diff.......	9′ 27″ N.
		Lat. D. R.....	30° 55′ 00″ N.
		Cor. Lat.......	31° 04′ 27″ N.

The same worked with D. R. lat. in error in the opposite direction.

Lat. D. R........	31° 14′ 00″ N.
	90° 00′ 00″
Co-lat.........................	58° 46′ 00″
Dec............................	16° 20′ 48″
Calc. alt......................	75° 06′ 48″ S.
Correction....................	+ 4′ 39″
Cor. calc. alt..................	75° 11′ 27″ S.
Obs. alt........................	75° 21′ 00″ S.
Alt. diff.......................	9′ 33″ S.
Lat. D. R......................	31° 14′ 00″ N.
Cor. lat........................	31° 04′ 27″ N.

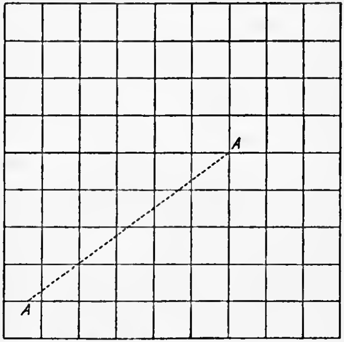
Plotting charts on which Sumner lines can be laid down are available. Capt. Fritz Uttmark, of the Nautical Academy, N. Y., has devised a special plotting chart for the St. Hilaire method. By it the correct place of the ship is quickly plotted.

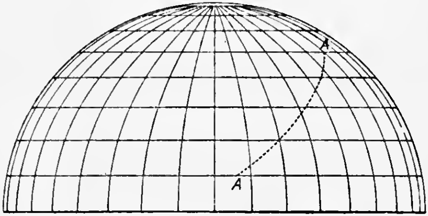
GREAT-CIRCLE SAILING

It is a peculiar fact that on a Mercator's chart a straight course between two places appears as a curve. This is owing to the expansion of the degrees of lat. and long. toward the poles, in order to construct the chart on the theory that the earth is a cylinder, as already explained. The converse is equally true: that a straight line ruled on a Mercator's chart is really a curve when you come to sail on it.

This is easily seen when you draw the two lines on flat or spherical surfaces. As the meridians of longitude constantly converge toward the poles, and as courses are all measured by the *angles they make with the meridians*, it naturally follows that when you draw the meridians all parallel to one another, you must be distorting an actual course when you make it cut all these meridians at the same angle. Drawn on a sphere, your straight course would become a curve, known as a rhumb line.

Great-circle charts can be obtained, and on them all great-circle tracks appear as straight lines. But Sir George Airy, Astronomer Royal, designed the following method of drawing a great-circle track on a Mercator's chart. Connect your points of departure and destination by a straight line. Find its





center by measurement, and draw a line at right angles and toward the equator. With the mid.-lat. between points of departure and destination, find "corresponding parallel" in the table on page 136. The perpendicular line must intersect this parallel.

With one point of the dividers in this intersection, with the other point describe a curve which will pass through the point of departure and that of destination. This curve will be the great-circle track.

Blank spaces in table arise from the fact that in such relations great-circle sailing is of no advantage. Within the tropics, for instance, it is of little use, because the distortion of the degrees on a Mercator's chart is so small.

A ship on a great-circle track, except when on the equator or sailing N. or S. true, must change her course often in order to keep on the track. Here the principle that a small arc of a large circle on the earth's surface is practically a straight line may be employed, and the successive courses laid off as usual with parallel rules and dividers. You may

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

find the distance on a great-circle course with close approximation by computing the lengths of these short courses and adding them.

To find the courses to be sailed, get the difference between the course at starting and that at the middle of the circle, and find how many quarter-points are contained in it. Divide the distance of half the great circle by this number of quarter-points, and that will give the number of miles to sail on each quarter-point course.

Suppose the course at starting to be N.E., and at the center E.N.E., and the distance from start to center 800 miles. The difference between N.E. and E.N.E. is 2 points, which = 8 quarter-points. Divide 800 by 8, and you get 100 miles for each quarter-point course. In other words, every 100 miles you change the true course a quarter of a point easterly.

Bear in mind that this means *true course.* Compass course must allow for variation and deviation.

Accurate method of measuring the distance on a G.-C. track.—Turn the largest course (always one of the end courses) into degrees. Then add the cosec. of the largest course, cosine of the smallest lat., and sine of the diff. of long. between the two places. Answer will be sine of the distance in degrees and minutes. As these are degrees and minutes of a great circle, which, like the equator, extends around the full circumference of the earth, multiply the degrees by 60 and add the minutes, and the result is the distance required.

If the sine of the distance gives more than 90°, subtract the angle from 180°, and use the sine of the remainder.

DISTANCE AND DANGER ANGLES

When a light or mountain first appears above the horizon, take its compass bearing and consult Table 6, Bowditch, which gives the distance at which elevated objects can be seen at sea. The height of the eye must also be considered. Thus:

At sea, running for Block Island Channel, Block Island Light, 204 ft. above the level of the sea, appeared above the horizon. Observer on bridge 25 ft. above sea. Required distance of light.

Table 6	.....200 ft.	=	18.63 miles' range of visibility.
" 6	..... 25 ft.	=	6.59 " " "
			25.22 miles, distance of light.

Uncommon refraction will sometimes make a light appear sooner than it ought to, and the navigator must be on the lookout for such phenomena. In fact, the whole operation is not to be accepted as infallible, for at the best it gives uncertain results.

The vertical angle of an object above the water-line, measured by the sextant, may also be used to give the distance. The navigator should possess Captain Lecky's *Danger Angle and Off-Shore Distance Tables*, in which are given the sextant angles for heights up to 1,000 ft. The vertical angle can be used with these tables when the object is partly below the horizon, or when it is between the horizon and the observer. Tables 33 and 34, Bowditch, are used in the navy. If the object is far away, and the angle consequently very small, it should be measured both on and off the arc. For instance, with a lighthouse, first bring down the center of the lantern (just as you would bring the sun) to the horizon, and read the angle. Then bring *up* the horizon line to the center of the lantern by moving the index bar of the sextant toward you, and read that angle. Take the mean of the two, and enter the tables under the height of the light. Opposite the sextant angle (or the nearest one to it) take out the distance. With a mountain bring down the top to the horizon. If the object is between you and the horizon, use the object's water-line.

Example: Oct. 5, 1917, bound west, passing Shinnecock Light, bearing N.-by-W.-½W. by compass, desired to know distance of ship from it. Vertical sextant angle, from center of light to water-line, measured on and off, 22′45″.

In table under 160 ft. and opposite 22′ 50″, distance given is 4 miles.

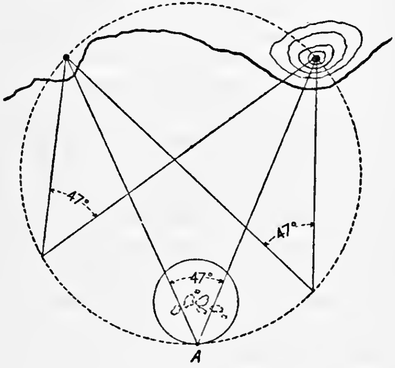
Aboard U. S. men-of-war the stadimeter or range-finder may be used to find the distance of any object on shore not beyond its limits.

For passing concealed dangers the vertical sextant angle is used thus: Suppose that 300 yards to the eastward of a light 45 ft. high, which you must pass on the easterly side, lies a shoal spot or a reef dangerous to you. You therefore decide to pass 300 yards outside of it, or 600 yards from the light. Under 45 ft. and opposite 600 yards you find the angle 1° 26′. You set the sextant at that angle, and watch for the image of the light in the horizon-glass. As long as the angle between the light and the water-line is 1° 26′ or *less*, you are 600 yards or more from the light. If the angle becomes more, you are inside of 600 yards. You need not move the index bar at all, for if the light rises above the water-line as seen in the horizon-glass, the angle is larger than that set, and in this case that means danger; but if it drops below, the angle is smaller.

The horizontal danger angle is at times extremely valuable, and the navigator should master its use. It is first necessary to learn to take horizontal angles with the sextant. Hold the instrument face up. Look through the sight-vane and horizon-glass at the left-hand object, and push the index bar forward till the right-hand object makes contact with it. Then read the angle.

It is a good plan to take cross-bearings this way, noting the compass bearing of one of the objects. The bearing of the other is at once known by the angle between the two. If the ship's head should fall off between the bearings, and change the deviation, you would have only one deviation to apply.

The horizontal danger angle is used in passing hidden dangers. Suppose you wish to pass at a distance of a quarter of a mile outside of some hidden rocks, and on the shore are certain objects, say a lighthouse and a mountain marked on the chart. Draw a circle around the rocks with a radius of a quarter of a mile. Now describe another circle that will pass through the lighthouse, the church, and the most seaward part of your first circle. From this last point, A, draw lines to the lighthouse and the church. Now measure with a protractor the angle at the juncture of these two lines. Set that angle (47° in the diagram) on the sextant, and watch the selected objects with instrument face up. The moment your two objects appear in the horizon-glass you are close to your circle of safety, and when they make contact you are on it. All you have to do is to alter the course of the ship so as to keep the contact, and so sail around the outer part of your circle till you have rounded the rocks. If you watch the angle closely this cannot fail, and in narrow waters it is an invaluable method.

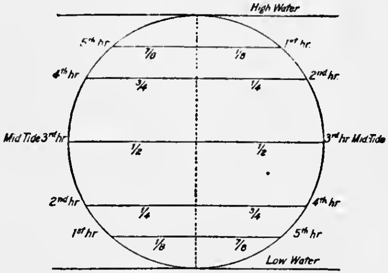


In measuring vertical danger angles get as close to the water as possible, so as to remove error of H. of E. But this will increase your angle and thus place you farther away from your danger, which is well, provided there is no other danger on the other side.

ALLOWANCE FOR TIDES

In fixing positions by lights, mountains, etc., in passing over shoals and in selecting anchorage, remember that heights recorded on charts are measured from *high* water, ordinary spring tides, while *soundings* are for *mean low water.*

To find the rise of the tide or its fall.—Use the following diagram:



The right-hand side shows how the tide falls = $\frac{1}{8}$ of its range for the first hour, $\frac{1}{4}$ at the end of the second, $\frac{1}{2}$ at the end of the third, and so on. The left-hand side shows how it rises.

Remember that the rise and fall do not coincide with the change of tidal current. You must ascertain the duration of the ebb and flow from the published sailing directions, such as the *Atlantic Coast Pilot.*

Where the range of the tide is great, you must allow for it in measuring angular altitudes of shore marks.

RATING A CHRONOMETER

It is sometimes necessary on a long voyage to ascertain the daily gain or loss of the chronometer, owing to the fact that the rate may be affected by extremes of temperature or other causes. The navigator may be far away from a maker, and hence must know how to ascertain the rate for himself. To perform the operation he will require an artificial horizon. This consists of a small trough, which is filled with absolutely clean mercury, and covered with a glass case which permits the observer to see the reflecting surface, and yet keeps wind and dust away from it.

The observer must now go with his sextant, chronometer, and artificial horizon to a spot where the longitude is accurately known to a fraction of a second. This will obviously be on shore, and that is why the artificial horizon must be used.

The observer should station himself, sitting, if possible, so that the artificial horizon will be in a direct line between himself and the body to be observed, and the image of the body will be shown in the mercury. Look through the sight-vane of the sextant, so as to see the image in the mercury through the horizon-glass. Bring down the image reflected by the sextant mirror till it makes contact with the image in the mercury. At that instant note the chronom. time.

If the obs. body is rising (east of merid.) the two images in the horizon-glass will separate, provided you are using the lower limb. If the body is sinking (west of merid.) they will close.

The angle of altitude shown by the sextant will be double what it would be with a sea horizon, and must therefore be divided by 2. The altitude is corrected as usual, except for height of the eye, which does not exist in this operation.

The remainder of the operation consists of finding the local mean time, and, by applying the longitude, the correct G. M. T. at the instant of observation. Thus the error of the chronom. is found. The observer now waits not less than six days (ten days are better), and then repeats the process at the same place. From the difference in the error on the two dates you get the daily rate.

Example: May 20, 1918. At St. Anthony Point Light, Falmouth, Eng., Long. 5° 01′ W., with artificial horizon obtained alt. which gave L. M. T. 6 hrs., 50 min., 08 sec. Adding 20 min., 04 sec. (Falmouth long.) we get G. M. T., 7 hrs., 10 min., 12 sec. At the instant of obs. chronom. showed 7 hrs., 14 min., 18 sec. Chronom. fast of G. M. T., 4 min., 06 sec. May 28 obs. showed chronom. fast of G. M. T. 4 min., 09.2 sec.

May 20..............	4 m. 06 s.
May 28..............	4 m. 09.2 s.
Gain in 8 days........	3.2 s.

$$\text{Daily rate } \frac{3.2}{8} = .4 \text{ sec.}$$

Other celestial bodies can be used as well as the sun. In many ports chronometers may be rated by public time signals, such as time-balls or guns.

CARE OF A CHRONOMETER

(Condensed by permission of T. S. and J. D. Negus, from their paper read before the Naval Institute.)

Be careful in carrying a chronometer never to give it a horizontal twist. This motion will affect the balance to such an extent as to throw the chronometer a second or a second and a half out of time.

The gimbals must be secured so as to prevent the chronometer from swinging while being carried. There is a stay for this purpose. Aboard ship the instrument should be allowed to swing.

Keep a chronometer aboard ship always in its outside case, in an apartment well ventilated, yet free from draughts. Never put a chronometer near wood which is in contact with salt-water.

Never open the outside case except when winding or taking time.

In damp countries wrap a blanket around the outside case.

You cannot do too much to protect a chronometer from rust. A small spot will change the rate of the instrument.

Wind the chronometer every day at the same hour, unless it is an eight-day chronometer; then wind it once every week at the same time.

In winding, turn the chronometer bowl over in the gimbal slowly with the left hand, slide the valve by pressing the forefingers of the left hand against the nailpiece on the valve until the key-hole is uncovered, insert the winding-key with the right hand, and wind to the left till a decided stop is felt. After removing the key, do not let the chronometer of its own accord drop to its level, but let it down carefully until horizontal.

Never let a chronometer get within the magnetic influence of a compass or an electromagnet.

If a chronometer has run down and needs to be started, wait till the hands indicate the proper time, and then start it by a slight horizontal twist.

All chronometers reach their highest gaining or losing rate at a certain temperature. Those used in the United States Navy, made by Negus, reach their fastest rate at 70° F. Any exposure of the instrument to other temperatures will change the rate. The average temperature correction, as given by the makers, is .0025 second, multiplied by the square of the difference in the number of degrees of temperature. Thus, to find the correction to be made to the rate of a chronometer in a temperature of 80°, multiply .0025 by the square of the difference between 70° and 80°. A chronometer with a rate of + 1 sec. at 70° would show the following variations:

55°	60°	65°	70°	75°	80°	85°
+ .4375 s.	+ .75 s.	+ .9375 s.	+ 1 s.	+ .9375 s.	+ .75 s.	+ .4375 s.

Chronometers should be cleaned and oiled at least once every three years and a half.

Vessels destined for long voyages should carry three chronometers. If you have two and one goes wrong, you cannot tell which is in error. With three you can make daily comparisons.

Keep your chronometers away from iron. It affects their rate.

In carrying a chronometer, use the leather strap on the case. Do not swing the instrument or let it be knocked. To transport overland (by rail, for instance) put the chronometer in a basket on plenty of cotton or something else that will prevent jarring.

THE DAY'S WORK

Before leaving port ascertain the exact draught of your vessel. Also ascertain the height of your eye above the water-line at all points available for taking observations.

As soon as you are on open water fix the position of the ship by cross-bearings, by vertical or horizontal angle and compass bearing, or by compass and range-finder.

This is called taking departure, and is entered in the log opposite the hour thus: "Sandy Hook Lightship bearing S. 15° W., distant 2 miles, from which I take departure."

From the moment of taking departure begin the record of the course and distance for each hour in the log-book. Note reading of pat. log whenever course is changed or a sight taken.

In all your work make it an invariable practice to write the name or initials of each item in a formula, as T. C. A. (or h, the symbol), secant, cos., etc. This will save you frequent confusion and often error.

Ascertain at night from azimuth tables the hour when the sun will bear most nearly east next morning.

For this purpose local app. time need be known only approximately.

To ascertain watch time for taking morning sight compare watch with chronometer the night before. Get from N. A. sun's dec. for next A.M. and work up lat. by D. R. With these enter azimuth tables and find right time to take morning sight. An example will show the rest of the work.

July 18, 1918, you find that next morning about 8 A.M. your lat. will be 35° 10′ N., long. 60° 12′ W.

Azimuth table, lat. 35°, dec. 21°, shows that sun will bear 89° 34′ at 8 hrs., 10 min. A.M.

Cor. chronom. reading at time of watch comparison	12 h. 00 m. 20 s.
Equation of time	− 6 m. 01 s.
G. A. T. at comparison	11 h. 54 m. 19 s.
Long. 60° 12′ W. = 4 h. 00 m. 48 s.	4 h. 00 m. 48 s.
L. A. T. at time of comparison	7 h. 53 m. 31 s.
Watch T. at time of comparison	7 h. 34 m. 22 s.
Watch wrong on L. A. T. for 8 A.M. sight	19 m. 09 s. slow
Time of 89° 34′ azimuth	8 h. 10 m. 00 s.
Watch-time to take A.M. sight	7 h. 50 m. 51 s.

Hence take the sight when the watch shows 7 hrs., 51 min., and the sun will be on the P. V. When the watch shows 7 hrs., 51 min., the correct L. A. T. will be 8 hrs., 10 min., 08 sec.

In morning note comparison of hack watch or hack chronometer with standard chronometers.

Ascertain index error of sextant.

Take A.M. long. sights at time determined as above. Always take at least three sights at equal intervals of time. Use mean of altitudes and times in working out. This reduces possible errors.

Although the ship can be navigated by St. Hilaire method, at least one chronometer sight should be taken each day to keep the local time accurately checked up. This is important.

At time of such sight take bearing of sun by standard compass and ascertain the deviation.

Set ship's clocks by L. M. T. obtained by applying equation to L. A. T. computed from sight.

Lay down line of position at right angles to sun's true bearing. If any line of position has been obtained in early morning hours run it up and get ship's position as already explained.

If running at high speed, scouting, or approaching land, get other lines of position by St. Hilaire method between morning and noon sights.

Ascertain exact run of ship between A.M. sight and noon, and set clock for local time of noon according to long. To do this remember that watch must be set back for westerly change of long. and forward for easterly.

Enter Table 2 with the course and the hourly speed of ship as dist. Find the diff. long. made from 8 A.M. sight to 11 A.M.

Apply this to watch-time to ascertain error of watch (W.) at 11 A.M.

For example, at A.M. sight W. was 19 min., 08 sec. slow. Suppose your change of long. to 11 A.M. is 2 min., 45 sec. east, then at 11 W. is 21 min., 53 sec. slow, and the time to noon will be 1 hr., − 21 min., 53 sec. = 38 min., 07 sec. Now get the diff. long. for the ship's run in 38 min., 07 sec., which is the change between 11 A.M. and noon. Let us suppose it amounts to 30 sec. You will have this result:

Watch slow at 8 A.M. sight	19 m. 08 s.
Change to 11 A.M.	2 m. 45 s.
Change from 11 to L. A. noon	30 s.
Total change	22 m. 23 s.
Run to noon, 4 hrs. − 22 m. 23 s. =	3 h. 37 m. 37 s.
Run from A.M. sight to noon = knots per hr. multiplied by	3 h. 37 m. 37 s.

Prepare constant for noon obs. At 12 M. (app. T.) take merid. alt. Run up latest Sumner line to intersect lat. parallel and establish noon fix. If weather is cloudy, take ex-merid. before noon in case sun is covered at noon.

If, following the old method of taking only the A.M. and noon sights and bringing up the long. to noon by D. R., you may find your D. R. lat. considerably out. In this case enter Table 47 with the D. R. lat. at the top and the azimuth of obs. body at side, and take out correction called longitude factor. Multiply it by diff. between lat. by D. R. and lat. by obs. Result is correction to be applied to A.M. long., which can then be carried forward to noon by D. R. If diff. between lats. is of same name (N. or S.) as first letter of azimuth, alteration of long. must be made in the direction contrary to that of second letter of azimuth (E. or W.).

Fix by intersecting Sumner lines, located by St. Hilaire method, does not require this correction.

Owing to inevitable errors, a vessel's position is rarely determined within two miles. Therefore draw a circle with a radius of 2 miles, and regard the ship as possibly anywhere within it. Plot next course from circumference.

After obtaining correct noon position, compute course and distance made good in day's run.

Compute total course and dist. from port of departure; also from port of destination. Difference between position by D. R. and that by obs. alt. is usually attributed to current; errors in steering, etc., however, are as much responsible.

In the afternoon work time sight when the sun bears most nearly west. Or lay down afternoon position lines by St. Hilaire method.

As soon as stars are visible try to get a good fix by simultaneous observations of two, or star and planet. When possible continue this work at intervals through night watches.

Charts expressly made for plotting positions can be obtained. They save the sailing-chart from pencil-marks and rubber-smudges.

Before approaching land acquaint yourself with lights, fog signals, soundings, buoys, etc., as shown on chart.

Be ready to recognize any light as soon as seen. If flashing, time the length of flash and length of interval when light is still distant. This will aid in identification, and sometimes make it certain.

Before entering a harbor note ranges, length of courses to be steered between turning-points, etc. If danger angles have to be used, plot them beforehand.

Change course at precise turning-point. Note time and read patent log.

If weather is thick, steer from buoy to buoy along channel, allowing for tidal current. If you fail to make a buoy at the computed time, anchor at once.

On reaching your anchorage, plot your position on chart by two or three charted objects whose bearings give well-defined intersections.

COMPENSATION OF THE COMPASS

Under certain conditions the magnetic force of the earth communicates magnetism to iron by what is called induction. Hammering the metal causes some of this magnetism to persist, and what remains is called sub-permanent magnetism. This kind of magnetism originates in a ship while she is building, and is most potent in the line of the earth's magnetic poles. A ship built with her keel magnetic north and south would have her magnetic north pole at the bow and south at the stern.

The earth exerts also a horizontal and a vertical magnetism. The former is most powerful at the magnetic equator and least so at the magnetic pole, while the latter is strongest at the pole and zero at the equator. Magnetism induced by these forces affects horizontal and vertical soft iron, respectively, and is transient.

The results of the operation of these forces are deviations of the compass. These are of three kinds:

Semicircular dev. is due to the sub-permanent magnetism of the ship and induced magnetism of soft iron. At some point on the compass-card this force becomes *nil.* If you swing your ship to the right from this point you will find easterly dev. through the first semicircle and westerly through the second, till the zero point is reached again. Hence semicircular dev. is that in which the cause operates equally in opposite directions through the two semicircles.

Quadrantal dev. is that induced in soft iron by the earth's horizontal magnetic force. Deviations of this class change their sign every 90° and are hence named quadrantal.

Constant dev. is due to induction in horizontal soft iron irregularly placed in relation to the compass. There is also a heeling error.

Semicircular dev. is corrected by magnets placed athwartships and fore and aft near the compass. The binnacle has compartments for these magnets. They have one end red and the other blue, and you must remember that the latter attracts the north end of the needle.

Quadrantal dev. is corrected by placing hollow spheres of soft iron at equal distances on both sides of the compass. Constant dev. is not compensated because it is usually immaterial.

See that the ship is on an even keel, compass accurately centered in binnacle, all masses of iron or steel near compass in their customary positions, and all compensating correctors taken away.

Place the ship's head on N. or S. correct magnetic. For this purpose use the Pelorus. Set its lubber's point at N. Clamp the sight-vanes at the magnetic bearing (true bearing corrected to include variation) of the observed object, as shown by chart. Starboard or port helm till the observed object (whether distant one on shore or the sun) is seen through the vanes. The ship is now heading N., magnetic. The difference between the ship's head and N. on the compass-card is the deviation, E. if comp. bearing is to right of true, W. if it is to left. Thus, when Pelorus shows head to be N., if comp. shows head to be N. by E., there is one point E. dev. In using the sun the bearings may be calculated beforehand by use of azimuth tables and L. A. T.

Correct with thwartship magnets. Note whether N. point is drawn toward starboard or toward port. If to starboard, place magnet with blue end to port, and *vice versa.*

Having corrected N. or S., place ship's head E. or W., again by use of Pelorus. Correct with fore and aft magnets. If N. is drawn toward bow, blue ends of magnets go toward stern, and *vice versa.*

Place ship's head on the two remaining cardinal points and correct half the error found there by readjusting the magnets. Do not try to correct all or you will throw it back on the first two. If at any time when you have placed, say, three magnets pointing one way, they pull a little too much, try turning the lowest one the opposite way.

This completes the semi-circular corrections. To correct quadrantal error, put ship's head N.E., S.E., S.W., N.W., and get deviation on each. Mark E. deviations + and W. −.

Reverse the sign of deviations found on S.E. and N.W. Then add deviations having same sign, take difference between plus and minus quantities and prefix sign of greater to result. Divide this result by 4, retaining sign. You now have the quadrantal dev., which is almost always +. Unless the construction of the ship be changed or she loads with iron, this dev. will not change.

Example: Dev. on N. E. −6°, on S.E. − 62°, on S.W. + 32°, on N.W. + 48°

```
N.E.  − 6°                          S.E. + 62° (sign reversed)
N.W.  − 48° (sign reversed)         S.W. + 32°
      ------                             ------
      − 54°                              + 94°
                                         − 54°
                                         ------
                                      4) + 40°
                                         ------
                                         + 10° = Quad. dev.
```

To compensate, when sign is + put ship's head as many degrees *to the left* as the quadrantal dev. shows. Keep her steady and move the spheres in or out till dev. disappears.

Heeling error is corrected by a vertical bar in a tube inside the binnacle. The scientific correction requires mathematical calculations beyond the purpose of this book. At sea when the ship is rolling correct error by slowly raising or lowering bar till abnormal vibration of card ends. In a sailing-vessel, heeling one way for some time under canvas, error may be determined by an azimuth.

A Flinders bar (a bundle of soft iron rods in a case) secured vertically near the compass, is used to counteract the effect of change in inductive magnetism of soft iron in changing ship's latitude. It can be placed most accurately when the ship is on the equator.

Compasses show a tendency to *hang back* when one course, especially easterly or westerly, is steered a long time. If you steer W. a long time, expect unusual W. error if you turn to N., or E. error if you turn S. The same principle applies to E. courses. This sluggishness of the compass is increased by gun-fire.*

FINDING THE DEVIATION

In order to compensate a compass the deviations existing on all courses must be ascertained. The methods by which they are found are used again to determine the deviations remaining after compensation. There are four methods, each of which requires the ship to be swung slowly around a circle, by her own steam, by a tug, or at anchor either by the tide or by springs and hawsers. All observations should be made from the standard

* For more details, consult Bowditch, articles 83–129; Lecky's *Wrinkles in Practical Navigation*, chap. xii; *The A B C of Compass Adjustment*, by E. W. Owens; *Instructions for the Adjustment of Lord Kelvin's Patent Compass;* and *Compass Adjustments*, by Lieut. Wm. Appelbye-Robinson, U. S. N. R. F.

compass and the others may be corrected at the same time by comparison with it.

In a new iron or steel ship observations must be made every 15° all the way around. In subsequent corrections, or in a wooden ship, observations may be made on one-half or one-fourth the number. On each course the ship must be steadied for three or four minutes so that the card may come to rest and magnetic conditions be settled.

1.—Reciprocal bearings. One observer on shore sets a compass where there is no local magnetic influence; the other observer is at the ship's standard compass. On each course, as the ship swings, the observers at signal take each other's bearing. The reverse of the shore observer's bearing of the ship observer is the magnetic (having variation, but no deviation) bearing of the man on shore. The difference between this and the bearing shown by the standard compass is the dev. The observers should compare watches before beginning and time each observation to check records.

2.—By ranges. Two range marks, such as the Swash Channel lights, New York Bay, whose magnetic bearing is charted, can be used for compass comparison.

4.—By true bearing of celestial body. For the sun the L. A. T. and for a star, planet, or the moon the H. A. must be used in entering the azimuth tables, as already explained. If the celestial body has a declination greater than those contained in the tables its azimuth may be computed by the azimuth formula or ascertained from Table V in H. O. Book No. 200, for the use of which very clear directions are given.

Alt.-azimuth formula: add P. D., lat. and T. C. A. and find half-sum as in time sight. Diff., however, is now P. D.—half-sum (instead of T. C. A.). Add secant P. D., secant lat., cosine half-sum, and cosine diff. This gives cosine of half the azimuth, so multiply by 2 to get correct angle of bearing.

If the time is accurately known, you may use this formula: Sine H. A. + cosine dec. + secant alt. = sine azimuth.

By a distant object.—Select a well-defined object on shore at least one hundred times as far away from the ship as the diameter of her swing. Obtain its magnetic bearing from the chart, or by taking a compass ashore and placing it in range between the center of the ship's swing and the object, or by swinging ship and accepting the mean of all the bearings as the magnetic. Then compare compass bearings with this magnetic bearing. Observations should be tabulated for inspection and reference in some such manner as the following:

Observations for series of deviations, Aug. 10, 1891, at Coquimbo, Chile. Object observed, mountain. Magnetic bearing of mountain from mean of all compass bearings, N. 3° 04′ W.*

Swinging Port to Starboard		
Ship's Head by Standard Comp.	Bearing of Mountain by Standard Comp.	Deviation
N.	N. 4° 10′ W.	1° 30′ E.
N. by E.	7° 15′	4° 35′
N. N. E.	10° 15′	7° 35′
N. E. by N.	12° 20′	9° 40′
N. E.	13° 40′	11° 00′

This tabulation is carried out through the entire swinging, the ship being taken around first from port to starboard and then the opposite way.

THE NAPIER CURVE

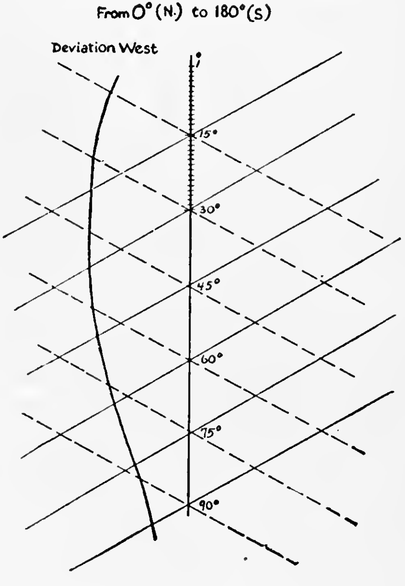
The most convenient way of recording deviations and correcting courses is by the use of the Napier curve. This is constructed by representing the circumference of the compass as a straight line and marking off on it the degrees from 0° to 360°.

Diagonally downward to the left at every 15° is drawn a plain line, and to the right a dotted line. These lines are inclined to the perpendicular at an angle of 60°.

The deviations are marked off with a curve as in diagram on page 162. In swinging

* *From Practical Problems and the Compensation of the Compass in the U. S. Navy.* Pub. by Navy Dept., 1898.

ship on every 15°, as before described, the deviation obtained on each course is measured off on the vertical scale and then laid off on one of the lines passing through the



This diagram shows the top of a Napier curve, represented by the heavy line, and the diagonals drawn through each interval of 15°. The straight perpendicular represents the circumference of the compass-card. From 180° to 360° would be placed to the right of the first half. We show here only the first quarter, **N. to E.**

point. If the deviations were observed on a *compass* course mark on the dotted line, right if E., left if W. If the deviations were observed on *magnetic* courses, mark on the plain line.

If the observations were not made on a 15° division, draw a parallel line through the degree representing the ship's heading. Mark each point thus obtained and draw a curve through them, as in the diagram, which is used as follows:

1. *Given the compass course, to find the corresponding magnetic course.*—Place one leg of a pair of dividers on the vertical line at the given compass degree; place the second leg on the curve where it intersects the dotted line passing through the given point, or where it intersects a line drawn parallel to the dotted line through the given course; swing the second leg from the curve to the vertical line, *downward* if the deviation be easterly, *upward* if westerly; the point where the second leg touches the vertical line will be the magnetic course required.

2. *Given the magnetic course, to find the corresponding compass course.*—Place one leg of a pair of dividers on the vertical line at the given magnetic course; place the second leg on the curve where it intersects the plain line passing through the given magnetic point, or where it intersects a line drawn parallel to the plain line through the given

point; swing the second leg from the curve to the vertical line, *upward* if the deviation be easterly, *downward* if westerly; the point where the second leg touches the vertical line will be the compass course required.

EXAMPLES FOR PRACTICE

DEAD-RECKONING

Suppose a ship to sail upon the following courses and distances: S.E.-by-S., 29 miles; N.N.E., 10; E.S.E., 50; E.N.E., 50; S.S.E., 10; N.E.-by-N., 29; W., 25; S.S.E., 10; W.S.W.½W., 42; N., 110; E ¾N., 62; N., 7; W., 62; N., 10; W., 8; S., 10; W., 62; S., 7; E.¾S., 62; S., 110; W.N.W.½W., 42; N.N.E., 10; and W., 25. Required the course and distance made good (Norie).

Ans. The ship has returned to the place she started from.

From lat. 40° 3′ N., long. 73° 28′ W., ship sails S.E.-by-S., 36 miles, variation ½ pt. west; S.E.-by-S., 8 miles, variation ¼ pt. west; S.E.½E., 28 miles, with half a point of leeway on the starboard tack and variation ¼ pt. west. Ship has been 8 hrs. in a current setting N.E. (variation ¼ pt. W.) at the rate of 2 knots per hr. Required lat. and long. in and course and distance made good (Patterson).

Ans. Lat. 39° 26′ N., long. 72° 07′ W., course S. 60° E., dist. 72 miles.

At 9.15 A.M. pat. log reading 15.3. Lat.

40° 28′ N., long. 73° 50′ W. Course per standard compass, 159°. Var. 11° W., dev. 3° E. until noon, when pat. log reads 50.7. Noon obs. gives lat. 40° 00′ N., long. 73° 32′ W. From noon to 4 P.M. course 150°, var. 10° W., dev. 4° E. Pat. log 4 P.M., 98.9. Time sight 4 P.M. gives long. 72° 59′ W. From 4 P.M. to 8 P.M. course, var. and dev. the same. Pat. log 8 P.M., 145.4. Required D. R. position 8 P.M.

Ans. Lat. 38° 43′36 ″ N., long. 72° 24′ W.

Noon position, lat. 10° 15′ S.; long. 150° 47′ W. Pat. log noon, 126.4. Noon to 4 P.M., comp. course 287°; var. 14° E.; dev. 3° E. Pat. log 4 P.M., 174.4. Time sight 4 P.M. gives long. 151° 36′ W. From 4 P.M. to 8 P.M. comp. course 300°; var. 16° E.; dev. 5° E. Pat. log 8 P.M., 223.8. Required 8 P.M. position of ship, course, and dist. made good since noon, and course and dist. to lat. 2° 20′ S., long. 161° 27′ W.

Ans. Lat. 9° 10′ 06″ N., long. 152° 07′ W. Course and dist. since noon, 309°, 104 miles. Course and dist. to go, 306°, 700 miles.

SHAPING COURSE BY MERCATOR'S SAILING

Required the bearing and distance of Pernambuco, lat. 8° 4′ S., long. 34° 53′ W., from Cape Verde, lat. 14° 45′ N., long. 17° 32′ W. (Norie).

Ans. S. 37° W. (217°), dist. 1715 miles.

Required course and distance from Cape Palmas, lat. 4° 24′ N., long. 7° 46′ W., to St. Paul de Loando, lat. 8° 48′ S., long. 13° 8′ E. (Norie).

Ans. S. 58° E. (122°), dist. 1481 miles.

LATITUDE BY MERIDIAN ALTITUDE OF SUN

At sea, merid. alt. ⊙ 38° 15′ 15″ S.; I. E., 1° 10′ −; H. of E., 15 ft.; chronom., 4 hrs., 10 min., 18 sec. P.M.; chronom. slow of G. M. T., 4 min., 37 sec.; dec., 4 P.M., 15° 30′ 11″ N., increasing; hourly var., 44.6″. Required lat. of ship.

Ans. 68° 14′ N.

At sea, merid. alt. ⊙ 48° 18′ 15″ N.; I. E., − 2′ 15″; H. of E., 20 ft.; G. M. T., 10 hrs., 26 min., 15 sec. A.M.; dec. noon, 19° 26′ S., decreasing; hourly var., .6′. Required lat. of ship.

Ans. 61° 17′ S.

LATITUDE BY MERIDIAN ALTITUDE OF STAR

At sea, Dec. 24, 1894. Merid. alt. ✳ Aldebaran 52° 36′ S.; no I. E.; H. of E., 20 ft.; dec. of ✳ 16° 17′ 52″ N. Required lat. of ship.

Ans. 53° 47¾′ N.

At sea, Dec. 26, 1894. Merid. alt. Sirius 36° 28′ S.; I. E., − 45″; H. of E., 14 ft.;

dec. of ✳, 16° 34′ 20″ S. Required lat. of ship.

Ans. 37° 3′ N.

LATITUDE BY EX-MERIDIAN ALTITUDES

At sea, July 12, 1885. Lat. by D. R. 50° N., long. by D. R. 40° W.; obs. ex-merid. alt. ⊙ 61° 48′ 30″; I. E., − 3′; dip, 3′ 48″; G. M. T. of obs., 2 hrs., 39 min., 9 sec.; dec. of ⊙ 2 P.M., 21° 54′ 18″ N.; hourly diff. dec., .3′, dec. decreasing; equation of time to be subtracted from M. T., 5 min., 20 sec.; hourly diff. equation, .3, equation decreasing. Required lat. of ship.

Ans. 49° 56′ N.

LATITUDE BY THE POLE-STAR

At sea, June 21, 1880. Lat. by D. R. 45° 20′ N., long. 37° 57′ W.; obs. alt. of Polaris, 44° 13′ 30″ N.; I. E., + 30″; H. of E., 32 ft.; G. M. T., 11° 45′ 20″; G. Sid. T. preceding noon, 6 hrs., 14 sec. Required lat. of ship (Lecky).

Ans. 45° 17′ N.

LONGITUDE BY CHRONOMETER SIGHT

Observed A.M. alt. ⊙ 20° 30′; chronom. 1 hr., 11 min., 19 sec. P.M.; chronom. 10 min., 20 sec. fast; H. of E., 10 ft.; lat. by D. R. 40° 15′ N.; dec. at noon, 13° 26′ 6″ S.; hourly diff. dec., .5′, dec. decreasing; equation of time, 14 min., 28 sec.; hourly diff. equation, .05″, equation decreasing; equation to be added to app. time. Required long. of ship (Patterson).

Ans. 58° 59′ 45″ W.

At sea Jan. 22, 1895. Obs. alt. of ☉ A.M. 17° 14′; G. M. T., 11 hrs., 42 min. A.M.; H. of E., 20 ft.; no I. E.; lat. 38° 50′ N.; dec. at noon, 23° 33″ S.; hourly diff., 12.48′, dec. decreasing; equation of time (to be subtracted from mean time), 3 min., 46.42 sec.; hourly diff. equation, 1.2 sec., equation increasing. Required long. of ship.

Ans. Long. 34° 18′ 30″ W.

At sea, Feb. 27, 1882. Lat. 40° 10′ 45″ N.; H. of E., 30 ft.; no I. E.; obs. alt. ✳ Procyon, 39° 11′ E.; G. M. T., 9 hrs., 58 min., 45 sec.; Sid. T. at G. at preceding noon, 22 hrs., 28 min., 52 sec.; dec. ✳, 5° 31′ 15″ N.; R. A. ✳, 7 hrs., 33 min., 10 sec. Required long. of ship, true bearing of star, and Sumner line (Lecky).

Ans. Long. 55° 40′ 15″ W.; true bearing of star, S. 58° E.; Sumner line, N. 32° E.

THE END

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