To find X, the D. Long. between A and V:
(refer to fig. 14·11)

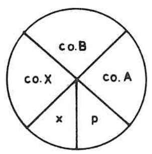


Fig. 14·11

$$\sin \text{co. } b = \tan \text{co. } X \tan \text{co. } A$$
$$\cos b = \cot X \cot A$$
$$\cot X = \cos b \tan A$$
$$\log \cos b = \bar{1}{\cdot}89152$$
$$\log \tan A = 0{\cdot}44883$$
$$\log \cot X = 0{\cdot}34035$$

$X = 24° 33'$

Long. $V = 34° 33'$ W.

To find y_1, y_2, y_3, y_4, the co-Lats. of a, b, c, and d
(refer to fig. 14·12)

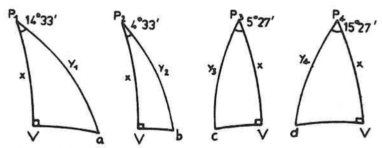


Fig. 14·12

$$\sin \text{co } P = \tan x \tan \text{co } y$$
$$\cos P = \tan x \cot y$$
$$\cot y = \cos P \cot x$$

Note—x has a constant value in the following computations

$\log \cos P_1 = \bar{1}{\cdot}98584$	$\log \cos P_2 = \bar{1}{\cdot}99863$
$\log \cot x = 0{\cdot}13529$	$\log \cot x = 0{\cdot}13529$
$\log \cot y_1 = 0{\cdot}12113$	$\log \cot y_2 = 0{\cdot}13392$
$y_1 = 37° 07'$	$y_2 = 36° 18'$
Lat. $a = 52° 53'$ N.	Lat. $b = 53° 42'$ N.
$\log \cos P_3 = \bar{1}{\cdot}99803$	$\log \cos P_4 = \bar{1}{\cdot}98402$
$\log \cot x = 0{\cdot}13529$	$\log \cot x = 0{\cdot}13529$
$\log \cot y_3 = 0{\cdot}13332$	$\log \cot y_4 = 0{\cdot}11931$
$Y_3 = 36° 20'$	$y_4 = 37° 14'$
Lat. $c = 53° 40'$ N.	Lat. $d = 52° 46'$ N.

Answers—Initial Course = 289½°
Distance = 1650 miles.

Positions of Points:
(*a*) Lat. 52° 53′ N. Long. 20° 00′ W.
(*b*) Lat. 53° 42′ N. Long. 30° 00′ W.
(*c*) Lat. 53° 40′ N. Long. 40° 00′ W.
(*d*) Lat. 52° 46′ N. Long. 50° 00′ W.

4. Composite Great Circle Sailing

It will be noticed in fig. 14·6 that every point on a great circle path is in a higher Latitude than the point on the rhumb line path which lies on the same meridian. The great circle path always carries a vessel into Latitudes higher than does the rhumb line path between the same two places. Many great circle paths climb into very high Latitudes and are, accordingly, unsuitable for navigation. Other great circle arcs are unsuitable for marine use because they cross land.

If it is desired to travel along the shortest route between two places, such that the Latitude of the ship during the voyage is never greater than some given value, the route to follow is a Composite route, involving a great circle path from the initial position to a point on the limiting parallel; thence along the limiting parallel; and finally along a second great circle path to the destination. The middle part of the route, along the limiting parallel of Latitude, extends betwen the vertex of the first great circle path to the vertex of the second great circle path. In other words the vertices of the two great circle arcs both lie on the limiting parallel of Latitude.

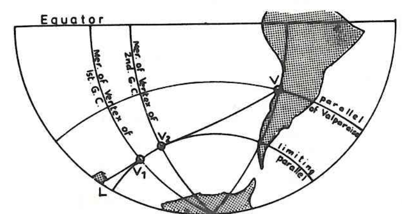


Fig. 14·13

Fig. 14·13 illustrates the composite great circle path between Port Lyttleton and Valparaiso. The limiting parallel of Latitude for this particular route is taken to be Lat. 50° 00′ S.

The tedious task of computing the initial and final courses, the distance, and positions of points along the track, resolves itself into solving two right-angled spherical triangles and a Parallel Sailing problem. In practice, a gnomonic chart would normallly be used to facilitate Composite Great Circle Sailing.

The following example, which is illustrated by fig. 14·14, serves to show how a Composite Great Circle sailing problem is computed.

Example 14·3—Find the distance and the initial course for the composite track from a position off the Cape in Lat. 40° 00′ S. Long. 20° 00′ E., to a position off Tasmania in Lat. 12° 00′ S. Long. 145° 00′ E. The limiting Latitude is to be 48° 00′ S.

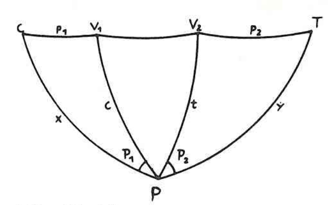


Fig. 14·14

Given:

$$x = 50° 00'$$
$$y = 70° 00'$$
$$c = 42° 00'$$
$$t = 42° 00'$$

Find p_1, P_1 and C for Distance, D. Long., and Initial Course, in the triangle PCV_1.

Find p_2 P_2 in triangle PTV_2, for Distance and D. Long.

In Triangle PCV_1:

$\sin \text{co}\, x = \cos p \cos c$
$\cos p = \cos x \sec c$
$\cos P = \cot x \tan c$

$\log \cos x = \bar{1}{\cdot}80807$
$\log \sec c = 0{\cdot}12893$
$\log \cos P_1 = \bar{1}{\cdot}93700$
$P_1 = 30° 07'$

$\log \cot x = \bar{1}{\cdot}92381$
$\log \tan c = \bar{1}{\cdot}95444$
$\log \cos P_1 = \bar{1}{\cdot}87825$
$P_1 = 40° 56'$

Distance = 1807 miles

$\sin c = \sin C \,.\, \sin x$
$\sin C = \text{cosec}\, x \,.\, \sin c$

$\log \text{cosec}\, x = 0{\cdot}11575$
$\log \sin c = \bar{1}{\cdot}82551$
$\log \sin C = \bar{1}{\cdot}94126$

$C = 60° 52'$
Initial Course = 119°

In Triangle PTV_2.

$\sin \text{co}\, y = \cos p \cos t$
$\cos p = \cos y \sec t$
$\cos P = \cot y \tan t$

$\log \cos y = \bar{1}{\cdot}31788$
$\log \sec t = 0{\cdot}12893$
$\log \cos p_2 = \bar{1}{\cdot}44681$
$p_2 = 73° 45'$
Distance = 4425 miles

$\log \cot y = \bar{1}{\cdot}32748$
$\log \tan t = \bar{1}{\cdot}95444$
$\log \cos P_2 = \bar{1}{\cdot}28192$
$P_2 = 78° 58'$

Long. P = 20° 00′ E.
D. Long. (P_1) = 40° 56′
Long. (V_1) = 60° 56′ E.

Long. T = 145° 00′ E.
D. Long. (P_2) = 78° 58′
Long. (V_2) = 66° 02′ E.

D. Long. V_1V_2 = 5° 6′
= 366′

From Traverse Table:

Dep. = 245 miles

Total Distance = p_1 + Dep. + p_2
= 1807 + 245 + 4425
= 6477 miles

Answers—Initial Course = 119°
Distance = 6477 miles.

Exercises on Chapter 14

1. Compare Great Circle Sailing with Rhumb Line Sailing.
2. In what circumstances does Great Circle Sailing provide the most economical route?
3. State the two disadvantages of Great Circle Sailing.
4. Describe the properties of a gnomonic projection.
5. Define Polar Gnomonic; Transverse Gnomonic; and Oblique Gnomonic Projections.
6. Describe how a polar gnomonic projection is constructed.
7. What is the radius of parallel of Latitude 65° on a polar gnomonic projection constructed from a model globe of radius 16·500 inches?
8. Explain carefully how a gnomonic chart is used to facilitate Great Circle Sailing.
9. In the absence of a gnomonic chart how would you lay down a great circle path on a Mercator Chart?
10. Find out how *ABC* and Azimuth tables are used to facilitate Great Circle Sailing.
11. What is meant by the vertex of a great circle?
12. The northern vertex of a great circle is in Lat. 36° 25′ N. Long. 126° 18′ E. What is the position of the southern vertex?
13. In what circumstances do the vertex of a great circle route lie (*a*) within and (*b*) outside the route?
14. The Initial Course is 072°. The Final Course is 168°. Where does the vertex of this Great Circle route lie relative to the final position?
15. What is a Composite Great Circle route?
16. Prove that the shortest route between two places when the ship is not permitted to sail polewards of a given Latitude is a Composite Great Circle route.
17. Describe the appearance of a Composite Great Circle route on (*a*) a Mercator Chart and (*b*) a polar gnomonic chart.
18. A great circle cuts the equator in Long. 40° 00′ W. at an angle of 29° with the meridian. What is the position of the northern vertex.
19. A vessel on a great circle track crosses the equator on a course of 060° in Long. 170° E. What is the position of the southern vertex of the great circle along which the ship is sailing?
20. A vessel on a great circle track has a course of 090° in Lat. 40° 10′ N. Long. 160° 00′ E, Where does this great circle cross the equator, and what angle does it make on crossing the equator?
21. Find the great circle Distance and the Initial Course from a position off the Lizard in Lat. 49° 50′ N. Long. 05° 15′ W. to a position off the Bermudas in Lat. 32° 29′ N. Long. 64° 00′ W. Find the positions of the points along the route which differ by 10° of Longitude from the Longitude of the vertex.
22. Find the great circle Distance and the Initial Course from a position off Newfoundland in Lat. 46° 20′ N. Long. 53° 00′ W., to a position off San Salvador in Lat. 24° 10′ N. Long. 74° 15′ W.

23. Find the Initial Course and the Distance along the great circle route from a position off Gibraltar in Lat. 36° 00′ N. Long. 06° 00′ W. to a position in the Mona Passage in Lat. 19° 00′ N. Long. 68° 00′ W. Find the positions of points along the route whose Longitudes differ by multiples of 10° from 10° W.
24. Find the Initial Course and the Great Circle Distance from a position off New Zealand in Lat. 38° 00′ S. Long. 179° 00′ E. to a position in the Gulf of Panama in Lat. 06° 00′ N. Long. 79° 00′ W.
25. Find the Great Circle Distance and the Initial Course from a position off the Cape of Good Hope in Lat. 39° 00′ S. Long. 20° 00′ W. to a position in the Bass Strait in Lat. 40° 00′ S. Long. 142° 00′ E.
26. Find the Initial Course and the Distance along the composite great circle route from *A* in Lat. 42° 00′ S. Long. 175° 00′ E. to *B* in Lat. 56° 00′ S. Long. 70° 00′ W., so that the maximum Latitude is 56° 00′ S.
27. Find the Initial Course and the Distance along the composite great circle route from a position off the S.W. coast of Ireland in Lat. 51° 20′ N. Long. 10° 00′ W. to a position in the Bell Isle Strait in Lat. 52° 00′ N. Long. 55° 00′ W., so that the limiting parallel is 53° 00′ N. Calculate the positions of points on the route which differ by multiples of 10° of Longitude from Longitude 20° 00′ W.
28. What is the least distance from the North Pole of an aircraft flying on a great circle route from Tokyo in Lat. 35° 40′ N. Long. 139° 46′ E. to Bergen in Lat. 60° 24′ N. Long. 05° 19′ E?

PART 3

INTRODUCTION TO CHARTWORK

Part 3, which comprises Chapters 15 to 24 inclusive, deals essentially with Coastal Navigation, in which the Chart and Compass are the principal instruments used by navigators.

Following a general discussion on charts and their use, consideration is given to the several methods of establishing a vessel's position—or "fixing" as the navigator describes the process—from observations of charted land- or sea-marks.

In many sea areas, especially those of North-West Europe, the range of the tide is of great importance when navigating coastwise. In such areas the mariner, especially when his vessel is close inshore, pays particular attention to the depth of water under his vessel's keel: the possibility of running aground because of insufficient water in tidal regions, should always be in the mind of the prudent navigator. A description of the tide and of its importance in navigation is, therefore, included in this part of the book.

CHAPTER 15

INTRODUCTION TO CHARTWORK

1. Coastal Navigation

Coastal Navigation is that branch of the main subject which includes the various methods of ascertaining the position of a vessel from observations of lighthouses, beacons and other conspicuous land- or sea-marks. Many of the methods used are based on geometrical principles. It is desireable, therefore, for a navigator to have a good working knowledge of the fundamentals of plane geometry so that he is able to understand the principles of the methods he may use.

2. Charts

A chart is a map used by a navigator. Depicted on a chart is all the essential data that may assist him in navigating his vessel. Charts may be classified into four main groups according to the specific purpose they serve.

(i) *Ocean Charts*—Ocean charts are small-scale charts used mainly for deep sea navigation. For this reason coastal detail is not depicted. A small-scale chart is one on which a relatively long distance of the Earth's surface is represented by a relatively short distance on the chart. A large-scale chart, on the other hand, is one on which a relatively short distance of the Earth is represented by a relatively long distance on the chart.

(ii) *Coastal Charts*—Coastal charts are large-scale charts used when navigating close inshore. Included in the considerable information given on a coastal chart are: the nature of the shore and coastline; positions and characteristics of lights, radio beacons, towers, and other prominent features observable from the offing, which may aid the coastal navigator; depths of water; current and tidal information; and positions of rocks, shoals, buoys and other floating and fixed sea-marks.

(iii) *Plan Charts*—Plans are very large-scale charts on which are depicted detailed information of small areas such as harbours or estuaries.

(iv) *Miscellaneous Charts*—In this group are included all those charts that are not included in the other groups. These are: gnomonic charts for facilitating great circle sailing; charts of the magnetic elements of the Earth, lattice charts for use with hyperbolic navigational systems, route charts, and wind and current charts.

3. The Natural Scale of a Chart

The natural scale of a chart is the ratio, expressed as a fraction, between a unit of length on the chart and the number of such units of the Earth's surface which it represents. If say, 1 cm. on a chart represents 1 km. on the Earth, the natural scale of the chart is 1/100000. If 1 cm. on the chart represents one nautical mile the natural scale is 1/185200, because there are 1852 metres in 1 nautical mile.

On a Mercator chart, the scale will vary with latitude, so a reference latitude is given alongside the scale. This latitude will normally be somewhere near the middle of the latitude covered by the chart.

For any latitude 0°, we define the natural scale as:

$$\text{Natural scale} = \frac{\text{length of 1 mile on the chart}}{\text{length of 1 mile on the earth's surface}}$$

(Both in same units)

But, 1 nautical mile is defined as 1′ of latitude so we get—

$$\text{Natural scale} = \frac{\text{length of 1}' \text{ of latitude in } 0° \text{ latitude}}{\text{length of 1 nautical mile on earth}}$$

$$\text{or in any latitude} = \frac{\text{length of 1}' \text{ of latitude} \times \text{sec latitude}}{\text{length of 1 nautical mile on earth}}$$

Charts having a natural scale of more than 1/50000 are usually constructed on the gnomonic projection. Most plan charts are of this type. The area to be represented, in this case being relatively small, the tangential plane almost coincides with the spherical Earth's surface over the limits of the area charted. It should be noted that on plan charts parallels of latitude and meridians are not projected as straight lines, and that projected meridians do not cross projected parallels at 90°. However, lack of parallelism, of projected meridians and parallels is hardly detectable on most plans because of the smallness of the area represented.

Because of the advantages offered to the navigator by the Mercator projection all ocean and coastal charts employ this projection.

All vessels should be adequately equipped with up-to-date charts and Sailing Directions. Sailing Directions are supplied by the Hydrographic Department of the Navy to cover the world. These, familiarly known as Pilots, contain valuable information of assistance to navigators. The Pilots are complementary to the charts, and the relevant Pilot should be consulted before and during a voyage as necessary.

It is the duty of the Master of a vessel to ensure that his vessel is properly supplied with charts and Sailing Directions and other publications necessary for the safe navigation of his vessel. Compiling the requirements for a voyage, and seeing to it that the necessary charts and Pilots are on board before the commencement of the voyage, is the duty of the Navigating Officer.

The charts published by the Hydrographic Department of the Navy are amongst the best

procurable. The Department issues more than 4000 charts covering the whole world. The *Catalogue of Hydrographic Charts*, which is obtainable at small charge, contains detailed information of all the charts and sailing directions published by the Hydrographic Department. This information includes: sizes and scale of charts; limits of Latitudes and Longitudes; and dates of publication. The *Catalogue* also contains index maps from which a navigator may readily see what charts are necessary for a given voyage.

4. Description of a Chart

The margin of a chart contains much useful information. In the bottom right-hand corner will be found the Catalogue Number of the chart. The dimensions of the plate from which the chart is printed and particulars of the plate or reproduction method are also given in the bottom right-hand corner of the chart.

In the bottom left-hand corner of the chart will be found the inscription "Small Corrections". Small corrections are made by hand from information promulgated by the Hydrographic Department in small booklets published weekly, monthly, quarterly and annually. These booklets, entitled *Notices to Mariners*, contain details of changes to charted information. The Notices are numbered and, when a chart has been corrected from information given in a particular Notice, the number of the Notice is recorded on the chart. The year of the Notice is given in heavy type and the number of the Notice is given in light type, thus:

Small Corrections: **1970.** 16,87,96. **1971.** 40 87,

Temporary and Preliminary information should be inserted in pencil on the chart of largest scale, and recorded thus:

230/1970 (T) 363/1975 (P)

these meaning, respectively, that temporary information was placed on the chart on the 230th day of 1970, and preliminary information was placed on the chart on the 363rd day of 1975.

Any necessary large correction is made to a chart before it is issued. A large correction often necessitates a new edition of the chart. The date on which a large correction was made, or a new edition issued, is inserted in the middle of the lower margin of the chart.

The day on which the chart was printed is recorded by giving the day number of the year and the last two figures of the year number in the top right-hand corner of the chart. A chart printed on the 4th February 1975, for example would be marked 35·75.

The Title of a chart, usually found clear of the sea area, contains information which should be studied carefully before using the chart. Details given in the title include:

(i) Name of the area depicted.
(ii) Details of the survey.
(iii) Units (metres or fathoms) of depths.
(iv) Level below which charted depths are given.
(v) Natural Scale.
(vi) A note stating that bearings are true and given from seaward.
(vii) Certain abbreviations used.

A particular chart is described by giving its Title and Catalogue Number; the date of the edition; the date of printing, and the date of the latest small correction.

To distinguish a good chart from an indifferent one, the navigator may be assisted by the following:

(i) The date of the survey of the area depicted. In general, the more recent the survey the more reliable the chart.

(ii) Amount of detail charted. Lack of detail often indicates an incomplete survey. If the coastline, for example, is shown as a dotted instead of a full line, it is probable that the survey was incomplete.

(iii) The spacing of the charted depths. This affords a good indication of the value of a chart. Not only the number of soundings given, but their spacing and arrangement, provide good tests of the reliability of the chart. Charted depths of a well-surveyed area usually appear systematically in parallel or radial straight lines and there are no large areas where no depths are given. The soundings on a chart compiled from scanty survey material are marked here and there more or less haphazardly.

On metric charts published by the Hydrographic Department shore areas lying between the High Water line and the 5-metre isobath are tinted blue.

5. Chart Abbreviations and Symbols

All abbreviations and symbols employed on charts of the Hydrographic Department are given on Chart 5011. This chart should be studied carefully and the information it gives should be familiar to all coastal navigators.

The description of the nature of the sea bed is denoted by the initial letter of the deposit or material. In general, capital letters are used for nouns and small letters for descriptive words.

For purposes of identification navigational lights have a variety of charactertistics. A light which gives a continuous steady light is described as a Fixed Light which is denoted on the chart by the abbreviation F. A Flashing Light, which is denoted by Fl., is one in which the length of the eclipse period between the flashes is greater than the length of the flashes. An Occulting Light, denoted by Oc for single occulting and Oc(2) for group occulting, is one in which the length of the eclipse is less than that of the flash. Lights which exhibit flashes of the same length as the eclipses are known as Isophase Lights (Iso). Some lighthouses exhibit lights consisting of a combination of flashes of different lengths as letters of the Morse Code. These are called Morse Code Lights Mo(k).

A light that shows different colours on the same bearing or over the same arc of the horizon is called an Alternating Light, and is denoted on a chart by the abbreviation Al. A light that shows different colours on different arcs is called a Sector Light. These are indicated on the chart by dotted arcs, as shown in fig. 15·1.

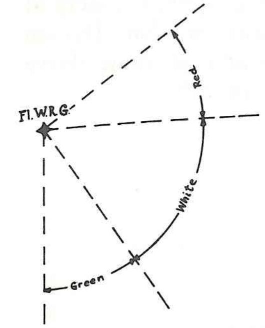


Fig. 15·1

The radii of the arcs of sector lights are not to be mistaken for the ranges of visibility. The light illustrated in fig. 15·1 shows Green from 330° to 000°; White from 270° to 330°; and Red from 240° to 270°. Remember that all bearings given on a chart are true and are given *FROM* seawards.

A light that flashes at a rate of 50 to more than 60 per minute is called a Quick Flashing Light, the abbreviations for Continuous Quick is Q, Group Quick is Q(3) and Interrupted Quick is (IQ).

Following the abbreviated description of the type of light the Period of the light is given. This is the interval in seconds for a complete sequence of the characteristic of the light.

The luminous range of a light is the maximum distance at which a light can be seen at given time, it depends on the intensity of the light and also the meteorological visibility. If it does not take into account of elevation, observer's height of eye or the curvature of the Earth. A diagram of luminous range is supplied with the Admiralty List of Lights. Nominal range is the luminous range when the meteorological visibility is 10 sea miles.

All lights are to be taken as being white unless otherwise indicated in which case R denotes Red and G denotes Green.

The abbreviated description of a light, red in colour, which exhibits a group of three flashes at intervals of 30 seconds, and which has a height above M.H.W.S. of 30 metres and a charted range of 15 miles is:

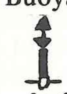
Gp Fl (3) R 30 secs 30 m 15 M

The charted information of this light on small-scale charts is less complete. On an ocean chart, for example, the abbreviated description might be:

Gp Fl R

In the symbol for a Light Vessel, which is , the small circle denotes the exact position of the light vessel.

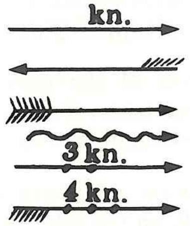
Buoys are depicted thus:  for conical;  for can-shaped; and  for spherical buoys including high focal plane  and spar . The International Association of Lighthouse Authorities (IALA) have introduced a new system of buoyage is called the IALA Buoyage System. Beacons with IALA system topmarks are charted by upright symbols eg.

 BYB,  R,  BRB. The colours and patterns of buoys are indicated by the following abbreviations:

B	Black
R	Red
Y	Yellow
G	Green
BWHB	Black and White Horizontal Bands
RWHS	Red and White Horizontal Stripes
RWCheq	Red and White Chequered

All charted heights on the land area of a chart are given in metres above the level of M.H.W.S. All depths, on the other hand, are given below a level which is approximately at the level of Lowest Astronomical Tide (L.A.T.). The actual level is known as Chart Datum (C.D.). Drying heights on banks and offshore zones are given in metres and decimals above the level of Chart Datum. The figures which indicate these heights are underlined.

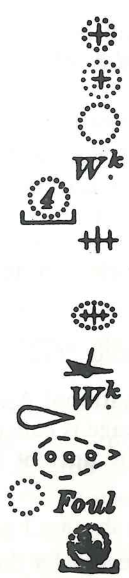
Tidal Stream and Current information is depicted thus:



Direction of ebb stream with rate
Direction of flood stream with rate
Direction of current with rate
Rate of Ebb is 3 knots 2 hours after H.W.
Rate of Flood is 4 knots 3 hours after L.W.

On some coastal chart tables of tidal stream information are given for certain reference positions on the chart which are donated thus:

The commonly used symbols for Wrecks, Rocks and other obstructions are:



Rock with less than 2 metres of water or less above it at Chart Datum.
Rock awash at chart Datum.
In general denoted a danger area.
Wreck, exact depth over it indicated.
Wreck over which the exact depth is unknown but thought to be more than 28 metres,—non-dangerous to surface navigation.
Dangerous wreck—depth unknown but is thought to be 28 metres or less.
Wreck with superstructure visible at L.W.
Wreck visible at L.W. (large-scale charts).
Wreck invisible at L.W. (large-scale charts).
Non-dangerous except for anchoring or trawling.
Swept by wire drag to depth indicated.

The sea-bed, especially in coastal waters, is often obstructed by submarine telegraph and power cables and with pipelines. It is important that vessels do not anchor in the vicinity of these. The location of cables and pipelines is indicated on charts published by the Hydrographic Department by a wavy line and a line composed of dots and dashes, respectively. These lines are usually given in magenta to render them conspicuous in artificial light.

A variety of fog signalling devices are in current use. These include the Diaphone,

denoted on charts by the abbreviation Fog Dia., which produces a very powerful air signal of low pitch, the sound ending with a distinctive grunt caused by the abrupt lowering of the pitch of the sound. The Nautophone, denoted by Fog Nauto., produces a note of high pitch, whereas the Reed, denoted by Fog Reed, gives a high pitch of power less than that of the nautophone. Other fog signalling devices include the Fog-Whistle, -Horn, -Gun, -Gong, -Siren, as well as the modern Tyfon.

Fog Detector Lights are sometimes incorporated at lighthouses and light vessels. A Fog Detector Light is a concentrated light of high frequency—and hence bluish in colour—which sweeps across the horizon, and which may be reflected by droplets of water in the atmosphere. The reflected energy triggers off a device which automatically sets the fog signalling apparatus in operation.

It is important to bear in mind that it is often difficult to estimate accurately the direction and range of a source of sound in fog. Areas sometimes exist in which a relatively strong sound signal is not heard even at short range. It is also important to realize that, although a vessel may be in fog, the weather may be clear at the location of a lighthouse or light vessel nearby, and the fog signalling appliances may not, therefore, be working. In these circumstances a navigator may feel falsely secure in not hearing a fog signal.

Symbols associated with radio and radar stations and beacons are coloured magenta.

⊙ R	denotes a coast radio station
⊙ Racon	denotes a Radar Responder Beacon
⊙ Ramark	denotes a Radar Beacon which transmits continuously and which provides information by means of which the navigator on a vessel in the vicinity may identify the beacon
⊙ Consul Bn	denotes a Consol Station
⊙ RG	denotes a Radio D.F. Station.

Admiralty chart no. 5011 provides a reference to many symbols and abbreviations found on Admiralty charts. From time to time revised editions are published to show symbols for features which have been introduced newly and to record other changes which are continually being made. The important changes are published in Admiralty Notices to Mariners. Throughout 5011, symbols and abbreviations no longer in use on new charts but still found on some older charts are marked as obsolescent.

6. Hints when using Charts

1. A chart in use at any time should be properly corrected from *Notices to Mariners* up to the time of its being used.
2. It is important to investigate any Cautionary Notices which are sometimes displayed in not-too-conspicuous positions on charts. These notices may include:

(i) Prohibited and Dangerous Areas.
(ii) Areas of Abnormal Variation.
(iii) Exceptional Tidal Streams.
(iv) Ice Warnings.

3. Always use the chart of largest scale available. The reasons for this include:
   (i) More detail is shown than on charts of smaller scale.
   (ii) Any plotting errors are reduced to a minimum.
   (iii) It is more up-to-date than charts of smaller scale. The plate of a large-scale chart is always corrected before those of smaller scale of the same area.
   (iv) Errors of distortion have the least effect.
4. When transferring a position from one chart to another use bearing and distance from a charted point common on both charts. Remember that the navigator is not so much interested in Latitude and Longitude as he is in his position relative to the land.
5. Ascertain the vessel's position as soon as possible after transferring from one chart to another.
6. Never have more than one chart on the table at any one time: the scales may be wrongly used.
7. A soft well-sharpened pencil should be used for all chart work: never harder than an HB and never softer than a B.
8. All courses should be checked and re-checked before setting.
9. Write information such as times of bearings, log readings, and so on, on that part of the chart which has been used: never clutter up the path ahead.
10. Use the meridian lines in conjunction with the parallel rulers for measuring course and bearing-angles, and for laying down course-lines.
11. Keep the chart storage space as dry as possible: a damp atmosphere often leads to distortion of charts.
12. Remember that a chart is an invaluable part of a vessel's equipment. Treat it with the respect that it deserves.

Exercises on Chapter 15

1. Distinguish between a Plan Chart, a Coastal Chart and an Ocean Chart.
2. Ask to see the chart outfit of your vessel. What miscellaneous charts are carried on board?
3. Distinguish between a small-scale chart and a large-scale chart.
4. What is meant by the Natural Scale of a chart?
5. What is the Natural Scale of a chart on which 1 inch represents (*a*) 10 nautical miles, (*b*) 1 cable?
6. The Natural Scale of a chart is 1/50000. What is its linear scale in cms. per nautical mile?
7. Describe fully the information to be found in the margin of a chart.
8. Describe the information found in the Title of a Chart.
9. What are Cautionary Notices?
10. Enumerate the features of a reliable chart.
11. Define: Flashing Light, Occulting Light, Group Flashing Light, Group Occulting Light.
12. Distinguish between an Alternating Light and a Sector Light.
13. Describe how the following sector light is depicted on a chart: Light shows Green from 040° to 160°, thence White from 160° to 350°. (*N.B.* Remember that bearings are true and that they are always given from seawards).
14. What tidal stream information may be given on a chart?

15. Describe the tables of tidal stream information that may be given on some coastal charts.
16. Describe the symbols used for depicting wrecks on charts.
17. Describe the *Chart Catalogue* published by the Hydrographic Department. Explain how you would draw up a list of the charts necessary for a given voyage.
18. What information is given in Sailing Directions? (Ask to examine a copy of the Sailing Directions, and study the contents).
19. What are *Notices to Mariners*? Explain how charts are kept up-to-date.
20. Describe the information pertaining to Radio and Radar stations that may be depicted on charts.
21. Describe the symbols for the various forms of fog-signalling devices.
22. What is a Fog Detector Light?

CHAPTER 16

CORRECTING THE COURSE

1. The Three Norths

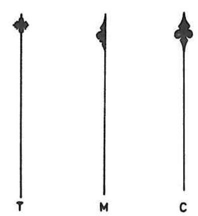


Fig. 16·1

(i) *True North*—This is the horizontal direction along the plane of any meridian towards the northern extremity of the Earth's axis of rotation.

(ii) *Magnetic North*—This is the horizontal direction indicated by the North-Seeking, or Red, end of a compass needle when it is under the influence of the Earth's magnetism and no other disturbing force.

(iii) *Compass North*—This is the horizontal direction indicated by the North-Seeking, or Red, end of the compass needle.

2. The Earth's Magnetism

The Earth has magnetic properties such that lines of magnetic force emanate from a position in south Victoria Land and follow approximate great circle paths to a position in Hudson Bay. These two positions are known, respectively, as the North and South Magnetic Poles.

The North Magnetic Pole of the Earth is said to have Blue Polarity, and the South magnetic Pole Red Polarity.

Every artificial magnet, such as a compass needle, has similar properties to those of the Earth-Magnet. The fundamental law of magnetism is that a force acts between any two magnetic poles. If the two poles are both Red or both Blue, the force is one of repulsion. If they have opposite polarities, the force is one of attraction. The Red end of a compass needle is attracted by the Earth's Blue pole. It is for this reason that the Red end of the compass needle is the North-Seeking end.

The magnetic force which endeavours to hold a compass needle in the plane of the magnetic meridian is very meagre: for this reason the compass needle is very easily disturbed. The chief disturbing force is that which results from the magnetism possessed by the vessel on board which the compass is housed. Cargo in the vessel may also have a disturbing influence. The vessel's magnetism is acquired by induction from the Earth-Magnet. The effect of the vessel's magnetism at the position of the compass usually results in the axis of the compass needle being forced out of the plane of the magnetic meridian. Thus, the directions of the three norths, defined in paragraph 1, are usually different from one another.

It will readily be appreciated that the courses and bearing laid down on a chart are related to True North, whereas courses steered by a helmsman, and bearings observed by a navigator, are related to Compass North. It is, therefore, necessary to convert courses and bearings from one system to another.

Conversion of courses and bearings from True to Compass, and *vice versa,* is a navigational duty which every responsible navigator will perform with the utmost care and with subsequent check.

3. The Three Courses

(i) *True Course*—This is the direction of a vessel's head relative to the direction of True North. It is the horizontal angle between the direction of True North and the vessel's fore-and-aft line ahead.

(ii) *Magnetic Course*—This is the horizontal angle between the directions of Magnetic North and the fore-and-aft line of the vessel in the forward direction.

(iii) *Compass Course*—This is the horizontal angle between the directions of Compass North and the fore-and-aft line of the vessel ahead.

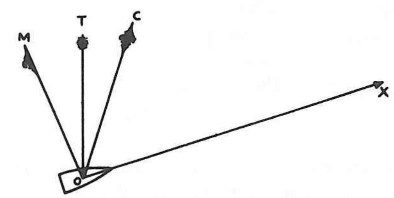


Fig. 16·2

Suppose that the vessel illustrated in fig. 16·2 is heading in the direction *OX*; and the *OT, OC* and *OM,* are the respective directions of True, Compass and Magnetic Norths, Then:

TOX = True Course
COX = Compass Course
MOX = Magnetic Course

4. The Three Bearings

(i) *True Bearing*—This is the horizontal angle between the directions of True North and "bearing" of an object. It is, in other words, the angle between the directions of True North and the object. Notice that the term "bearing" may be used in the sense of it being an angle or a direction.

(ii) *Magnetic Bearing*—This is the angle, in the horizontal plane, between the directions of Magnetic north and an object.

(iii) *Compass Bearing*—This is the horizontal angle between the directions of Compass North and the object.

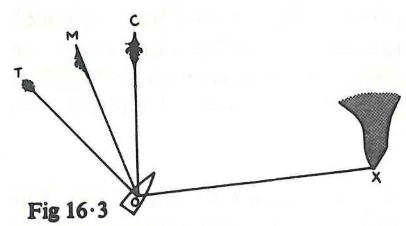


Fig 16·3

In fig. 16·3, *O* denotes the position of a vessel, *X* that of a point of land, and *OT, OM* and *OC,* denote, respectively, the directions of True North, Magnetic North and Compass North.

TOX = True Bearing of X
MOX = Magnetic Bearing of X
COX = Compass Bearing of X

5. Compass Error

Compass Error is the horizontal angle between the directions of True North and Compass North. When Compass North lies to the right of True North, Compass Error is named East. When Compass North lies to the left of True North, Compass Error is named West. The operation of converting True Courses and Bearings into their corresponding Compass Courses and Bearings requires the application of Compass Error. The process is simple provided that the conventional system of naming Compass Error, given above, is memorized. A rough diagram also assists, as indicated in the following examples.

Example 16·1—Find the Compass Course if the True Course is 070° and the Compass Error is 5° E.

In fig. 16·4:

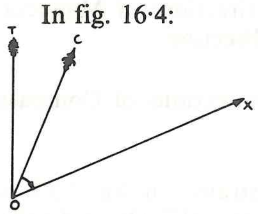


Fig. 16·4

OT = True North
OC = Compass North
TOC = Compass Error
OX is direction of vessel's heading
TOX = True Course = 070°
TOC = Compass Error = 5° E.

COX = Compass Course = 065°

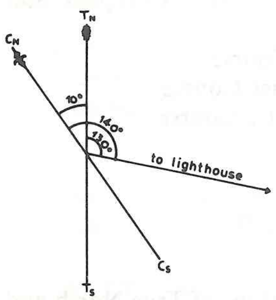


Fig. 16·5

Example 16·2—Find the True Bearing of a lighthouse if its Compass Bearing is 140° and the Compass Error is 10° W.

In fig. 16·5:

OT_N = True North
OC_N = Compass North
COT = Compass Error = 10° W.
COX = Compass Bearing = 140°
TOX = True Bearing = 130°

6. Variation

Variation is the horizontal angle between the directions of True and Magnetic Norths. It is defined as the angle between the True and Magnetic Meridians at any place.

When Magnetic North lies to the right of True North, the Variation is named East. When Magnetic north lies to the left of True North, Variation is named West.

The variation at any place may be found by inspection from a Variation Chart on which is drawn lines connecting places where the variation is the same. These lines are known as Isogonic lines or Isogonals: a Variation Chart is, therefore, sometimes known as an Isogonic Chart. The angle of variation is sometimes printed on the compass roses of navigational charts.

Variation at any place is not constant: it undergoes a gradual change with time. The navigator should be careful to apply any necessary secular correction to variation found from a chart for a date different from that of the year the chart was published.

Variation applied to a True Course or Bearing gives a corresponding Magnetic Course or Bearing, and *vice versa.*

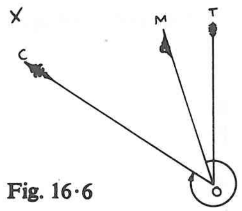


Fig. 16·6

Example 16·3—Find the Magnetic Course if the True Course is 320° and the Variation is 8° W.

In fig. 16·6:

TOX = True Course = 320°
TOM = Variation = 8° W.
MOX = Magnetic Course = 328°

Example 16·4—Find the True Bearing of a star if its Magnetic Bearing is S. 30° W. and the Variation is 6° E.

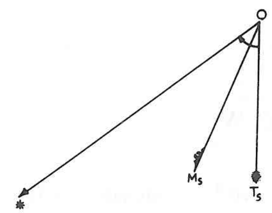


Fig. 16·7

In fig. 16·7:

MO★ = Magnetic Bearing = S.30° W.
TOM = Variation = 6° E.

TO★ = True Bearing = S.36° W. or 216°

7. Deviation

Deviation is the horizontal angle between the directions of Magnetic and Compass Norths. It is due to the magnetism of the vessel and/or her cargo. Deviation for an uncompensated compass normally changes with the vessel's course.

When Compass North lies to the right of Magnetic North, Deviation is named East: when Compass North lies to the left of Magnetic North, it is named West.

To convert a Compass Course or Bearing into a corresponding Magnetic Course or Bearing, or *vice versa,* Deviation must be applied.

Example 16·5—Find the Compass Course to steer a Magnetic Course of 030° if the Deviation for the ship's heading is known to be 10° E.

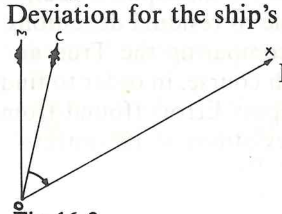


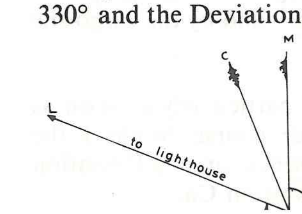
Fig. 16·8

In fig. 16·8:

MOX = Magnetic Course = 030°
MOC = Deviation = 10° E.

COX = Compass Course = 020°

Example 16·6—The Magnetic Bearing of a lighthouse is required. The Compass Bearing is 330° and the Deviation for the heading of the vessel, when the bearing was observed, is 5° W.



In fig. 16·9:

COL = Compass Bearing = 330°
MOC = Deviation = 5° W.

MOL = Magnetic Bearing = 325°

From the foregoing remarks it will be seen that the Compass Error is a combination of Variation and Deviation.

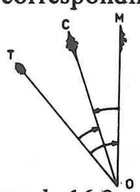
Example 16·7—Given Variation = 15° W., and Deviation = 5° E. Find the Compass Error.

In fig. 16·10:

TOM	= Variation	=	15° W.
MOC	= Deviation	=	5° E.
TOC	= Compass Error	=	10° W.

Fig. 16·10

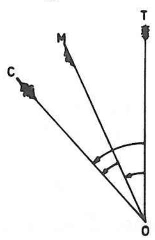
Example 16·8—Given Compass Error = 4° E., Variation = 15° E. Find the Deviation for the corresponding heading of the vessel.



In fig. 16·11:

TOC	= Compass Error	=	4° E.
TOM	= Variation	=	15° E.
MOC	= Deviation	=	11° W.

Example 16·9—Given Compass Error = 20° W., Variation 15° W. Find the deviation for the Corresponding heading of the vessel.



In fig. 16·12:

TOC	= Compass Error	=	20° W.
TOM	= Variation	=	15° W.
MOC	= Deviation	=	5° W.

Fig. 16·12

8. The Deviation Card or Table

An attempt is made to neutralize the magnetism of the vessel at the position of the magnetic compass, but complete success at doing so is not normally to be expected, and any uncompensated magnetism due to the vessel results in residual deviations. Before leaving harbour, and before making a landfall, whenever residual deviations for anticipated courses are not known it is wise to "swing" the vessel and to draw up a table of residual deviations. This is done by steadying the vessel on successive courses, and comparing the True and Compass Bearings of a fixed shore object or a celestial body, for each course, in order to find the deviation for that course. This is found by combining the Compass Errors (found from the observations) with the Variation. It is customary to find the deviations at 10°-intervals around the compass.

It should be borne in mind that the deviations shown on a Deviation Card apply only to the time and place at which they were determined. Deviation changes with geographical position and it may be affected by the condition of loading of the vessel, and by the cargo she has on board.

The deviations should be verified by observation frequently and particularly as soon as possible after each alteration of course. It is usual, when on a steady course, to check the deviation at least once each watch, and to record the details of the observation in a Deviation Book. On many vessels the Deviation Book serves as a working Deviation Card.

A Deviation Card may give deviations against Compass Course, Magnetic Course, or both Compass and Magnetic Courses. A portion of a Deviation Card of the latter type is illustrated below:

Compass Course	Deviation	Magnetic Course
000°	2° E.	002°
010°	3¾° E.	014°
020°	4¾° E.	025°
030°	5¼° E.	035°
040°	5¼° E.	045°
050°	4½° E.	054°
060°	3¼° E.	063°
070°	¾° E.	071°
080°	1⅔° W.	078°

If a graph of deviations against course is drawn it is an easy matter to find the deviation for any Compass of Magnetic Course. The Deviation Card given above produces curves of deviation which are illustrated in fig. 16·13.

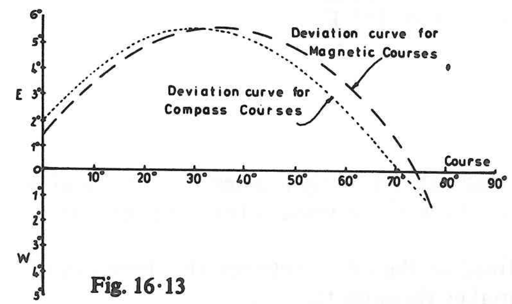


Fig. 16·13

In practice, instead of drawing a graph it is usual to assume that the deviation changes linearly between successive tabulated values given on the Deviation Card. In this circumstance the deviation for a course lying between tabulated values is found by simple proportion. The result obtained in this method is not strictly accurate but it is usually sufficiently accurate for practical purposes in which deviations to the nearest quarter of a degree are good enough.

The task of converting courses and bearings from True to Compass or from Compass to True is mastered only after considerable practice. It is recommended that novices draw diagrams to assist them in solving these very important problems. If the principles are learnt thoroughly there is no need to employ any of a profusion of mnemonical rules which, instead of helping students, often make confusion doubly sure.

Example 16·10—Find the Compass Course to steer a True Course of 336° if the variation is 10° W. Use the attached Deviation Card.

Compass Course	Deviation
000°	4° E.
350°	6° E.
340°	9° E.
330°	13° E.
320°	10° E.
310°	6° E.
300°	5° E.

True Course	=	336°
Variation	=	10° W.
Magnetic Course	=	346°
Deviation	=	11° E.
Compass Course	=	335°

Explanation of how the deviation was found:

Two adjacent compass courses were chosen such that when deviations were applied to them two magnetic courses were found. It was arranged that these lay one on each side of the magnetic course of the vessel, viz. 346°. The change in the deviation between one of the two magnetic headings found and the vessel's magnetic course was found by simple proportion. This change was applied to the chosen magnetic heading and the deviation for the vessel's magnetic course, therefore found. The computation is as follows:

Compass Course =	340°	Compass Course =	330°
Deviation =	9° E.	Deviation =	13° E.
Magnetic Course =	349°	Magnetic Course =	343°

For a change of 6° in Magnetic Course, Deviation changes 4°.
For a change of 1° in Magnetic Course, Deviation changes 4/6°.
For a change of 3° in Magnetic Course, Deviation changes 4/6 × 3°.

That is to say: 2°
Deviation on 349° (M) = 9° E.

Therefore: Deviation on 346° (M) = 11° E.

9. Leeway

When the wind blows in any direction except right ahead or right astern, the path of a vessel under way is orientated to leeward of the direction of the vessel's fore-and-aft line.

Leeway, which is illustrated in fig. 16·14, is defined as the angle between the direction of the fore-and-aft of a vessel and the direction she makes through the water.

The angle of leeway may be ascertained by facing aft at the stern of a vessel and estimating the angle between the fore-and-aft line and the direction of the wake. The amount of leeway depends upon the strength of the wind; the direction it blows relative to the vessel; and the areas of the profile of the vessel above and below the waterline.

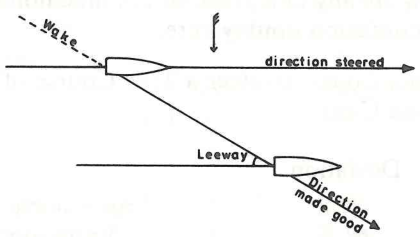


Fig. 16·14

In days of sail a semicircle was engraved on the taffrail of the vessel. The diametrical line of the semicircle was athwartships and the arc was marked in points and quarter points of the compass. At the centre of the semicircle was fitted a small swivel. Whenever the log was hove for measuring the speed of the vessel, before taking in the line it was slipped into the swivel, and the leeway read from the engraved semicircle.

Note that although a vessel proceeds along the direction she makes through the water, the vessel's head lies in the direction in which she is being steered, and it is this direction that governs the amount of compass deviation. Note also that the direction in which the vessel travels through the water is in the opposite direction to that of her wake, and that it is along this line that distance through the water is measured. A streamed log lies in the wake and it registers, therefore, the distance travelled through the water.

The two examples which follow should be studied carefully. Note particularly that in Example 16·11, in which it is required to find the Compass Course, the leeway is applied to the true course and to windward; in Example 16·12, in which it is required to find the True Course, and in which the Compass Course is given, the leeway is applied to the True Course again but to leeward. This is always the case: for finding Compass Course apply leeway to windward: but if given the Compass Course, apply leeway to leeward. Either way the leeway is always applied to the True Course only.

Example 16·11—Find the Compass Course to steer a True Course of 225°. Leeway due to a South wind is 10°; Variation is 5° E.; and deviation is obtainable from the attached Deviation Card.

Compass Course	Deviation
180°	4° W.
190°	1° W.
200°	2° E.
210°	6° E.
220°	9° E.
230°	10° E.
240°	3° E.
250°	2° W.
260°	6° W.

(C) =	200°	(C) =	210°
Deviation =	2° E.	Deviation =	6° E.
(M) =	202°	(M) =	216°

4/14 × 8° = 2°
Required deviation = 4° E.

True Course = 225°
Leeway = 10°

True Heading = 215°
Variation = 5° E.

Magnetic Course = 210°
Deviation = 4° E.

Compass Course = 206°

Example 16·12—The Compass Course is 220°. Find the True Course made good given that the Variation is 5° W., and the leeway due to a South wind is 10°, and that the deviation is obtainable from the Card given in Example 16·11.

Compass Course =	220°
Deviation =	9° E.
Magnetic Course =	229°
Variation =	5° W.
True Course through water =	224°
Leeway =	10°
True Course made good =	234°

Exercises on Chapter 16

1. Define: True North, Magnetic North, Compass North.
2. Define: True Bearing, Magnetic Bearing, Compass Bearing.
3. Define: True Course, Magnetic Course, Compass Course.
4. Define: Variation, Deviation, State the conventional rules for naming these angles.
5. What is Compass Error? Explain why compass Error normally changes with the heading of a vessel.
6. What is meant by Residual Deviations? What is a Card of Deviations?
7. Explain how deviation for a given Magnetic Course is found from a table of deviations for Compass Courses.
8. Describe Leeway and its compensation when finding distance made good over the ground.
9. Fill in the blank spaces in the following table:

Compass Course	Variation	Deviation	Compass Error	True Course
318°	5° W.	2° E.	—	—
178°	5° E.	—	—	183°
185°	10° E.	—	14° W.	—
—	4° W.	—	6° W.	082°
—	—	4° W.	10° E.	257°
000°	7° W.	2° W.	—	—
272°	—	5° W.	6° W.	—
114°	—	4° W.	10° E.	—

10. Whilst heading 200° (C) the Compass Bearing of a lighthouse was 304°. The True Bearing at the time was 292°. Find the deviation for the vessel's heading given that the variation is 16° W.
11. A point of land was abeam to port. The vessel's heading was 124° (C). The True Bearing of the point was 040°. Find the deviation for the vessel's heading given that the variation is 6° E.
12. Find the Compass Course to steer in order to counteract the effect of a southerly gale given that the True Course to make good is 070°; the variation is 8° E., and the leeway is 10°. Use the Deviation Card given on page 130.

13. The Course of a vessel is 320° (C). Variation = 5° E. Find the True Course made good if the wind is N.E. and the leeway is 5°. Use the Deviation Card given on page 123.
14. Convert the following True Courses into Compass Courses. Variation = 10° W. Use the Deviation Card given on page 125. (*a*) 120°, (*b*) 200°, (*c*) 176°, (*d*) 275°, (*e*) 265°.
15. Heading 157° (C) the following Compass bearings were observed. Lighthouse 317°, Steeple 242°, Peak 170°, Variation = 10° E. Find, using the Deviation Card given below, the corresponding True Bearings.

Compass Course	Deviation	Compass Course	Deviation
000°	4° E.	180°	10° W.
010°	7° E.	190°	13° W.
020°	12° E.	200°	15° W.
030°	14° E.	210°	17° W.
040°	16° E.	220°	18° W.
050°	17° E.	230°	19° W.
060°	18° E.	240°	19° W.
070°	18° E.	250°	19° W.
080°	17° E.	260°	16° W.
090°	16° E.	270°	13° W.
100°	14° E.	280°	9° W.
110°	12° E.	290°	5° W.
120°	10° E.	300°	2° W.
130°	7° E.	310°	1° E.
140°	3° E.	320°	4° E.
150°	1° W.	330°	6° E.
160°	5° W.	340°	9° E.
170°	7° W.	350°	7° E.

CHAPTER 17

THE POSITION LINE

1. Fixing by Cross Bearings

If the Compass Bearing of a lighthouse or other conspicuous shore mark is observed, and the Compass Error for the particular heading of the vessel applied, the True Bearing of the observed object is determined. This enables a navigator to project or plot a straight line on his chart and to say, with certainty, that his vessel's position may be fixed on that straight line. Such a line is called a Position Line.

A position line obtained from a bearing of a fixed terrestrial mark is drawn from the charted position of the mark in a direction opposite to that of the bearing of the mark. If, for example, a mark bears due North, the position line is drawn in a direction due South of the Charted position of the mark. Again, if a mark bears, say, 310°, the position line is drawn 130° from the charted position of the mark.

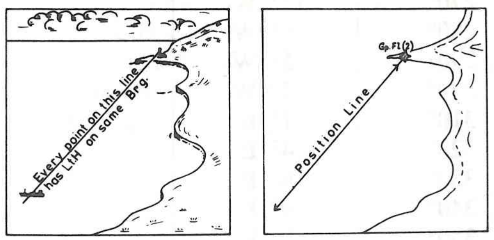


Fig. 17·1

Fig. 17·1 illustrates a position line obtained from a bearing of a lighthouse. It is customary to indicate a position line by means of single arrowheads as illustrated in fig. 17·1.

It is impossible to ascertain a vessel's position from a single position line. Before a fix is possible two pieces of information are required. The most common and perhaps the most reliable, method of fixing is by simultaneous observations of the bearings of each of two conspicuous and suitably-placed shore marks, thus obtaining two position lines, This method of fixing is illustrated in fig. 17·2, in which it is evident that the fix is at the intersection of the two position lines.

In practice, when possible, it is usual to observe three bearings, thus to obtain three position lines. The third bearing is referred to as a Check Bearing. This method of fixing a vessel is known as Fixing by Cross Bearings.

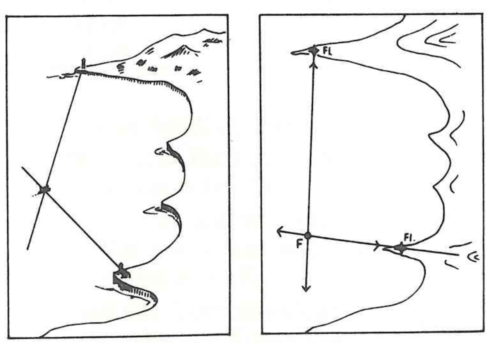


Fig. 17·2

It should be borne in mind that a position found from cross bearings is accurate only if the following conditions apply:

1. The bearings are accurately observed.
2. The Compass Error is known and properly applied.
3. The position lines are laid down accurately.
4. The charted positions of the observed marks are correct.

2. The Cocked Hat

When three position lines obtained from three simultaneous bearings are laid down on a chart they do not usually intersect at a common point. The probable reason for this is that one or more of the conditions stated above are not met. The three position lines usually form a small triangle which is known as a Cocked Hat.

When, on laying down three position lines they intersect to form a cocked hat, the navigator is given evidence of error of some sort. If, after careful checking, the cocked hat remains, the vessel's position is usually fixed at the apex of the triangle nearest to danger. This is illustrated in fig. 17·3.

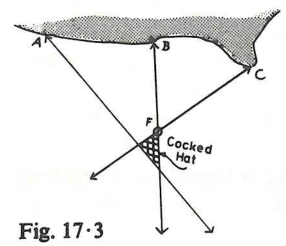


Fig. 17·3

If three position lines obtained, respectively, from the bearings of *A, B* and *C* are laid down on the chart as illustrated in fig. 17·3, the vessel's position would be reckoned to be at *F*.

3. Transits

Very frequently, when coasting, two charted shore marks are observed to lie in the same direction from the vessel. Such marks are said to be in Transit, and their bearing is said to be a Transit Bearing. A transit bearing affords an excellent means of finding or checking the Compass Error. The True Bearing of marks in transit may be found from the chart, and the difference between this and the Compass Bearing is the Compass Error for the particular heading of the vessel.

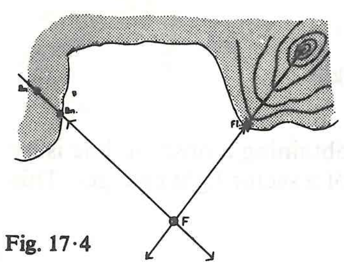


Fig. 17·4

Fig. 17·4 illustrates the method of fixing by means of transit bearings.

4. Relative Bearings

A relative Bearing of an object's bearing relative to the vessel's fore-and-aft line. It is the angle between the direction of the vessel's fore-and-aft line and that of the observed mark. The relative bearing of an object which lies in a direction 40° on the starboard bow is stated to be Green 040°. The relative bearing of an object which lies in a direction 120° on the port bow is stated to be Red 120°, and so on.

5. Fixing by Bearing and Angle

If it is desired to fix a vessel by cross bearings, and it is found that one of the marks to be observed cannot be seen at the compass position—it being obscured by a mast or funnel—a fix may be obtained from a single bearing and a horizontal angle measured by means of a sextant.

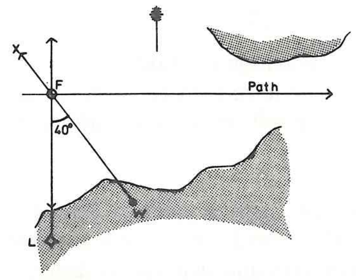


Fig 17·5

Fig. 17·5 illustrates the method of fixing by bearing and angle.

Suppose the vessel illustrated in fig. 17·5 to be heading 090°, and that the lighthouse *L* is abeam to starboard at the same time as the angle between the lighthouse and a windmill *W* is 40°. The vessel is fixed at *F* by first laying down the position line obtained from the bearing of the lighthouse, and then drawing the position line *WX* so that it cuts the first postition line at an angle of 40° The vessel is fixed at the intersection of the two position lines.

6. Fixing by Bearing and Sounding

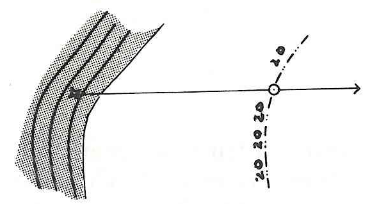


Fig. 17·6

A sounding often assists in fixing a vessel. A sounding is, in a sense, a vertical position line.

Suppose the beacon, illustrated in fig. 17·6, was observed to bear 270° at the same time as a corrected sounding was 20 metres. The vessel is fixed at the position where the position line obtained from the bearing of the beacon cuts the 20-metres isobath; provided, of course, that the position line cuts the sounding line in one place only.

7. Fixing by Sector Light

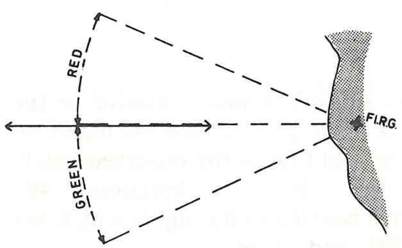


Fig. 17·7

A useful method of obtaining a position line is by noting when the colour of a sector light changes. This is illustrated in fig. 17·7.

Referring to fig. 17·7: if, from a vessel on a northerly course the colour of the light is seen to change from Green to Red, the vessel may be fixed on the dotted line on the chart which indicates the bearing of the lighthouse at the change of the colour of the light.

8. Choosing Marks for Fixing

When it is necessary to observe bearings for the purpose of fixing a vessel, it is better, when a choice is available, to observe near objects instead of more remote marks.

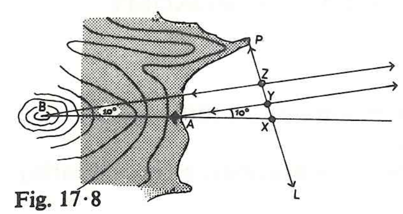


Fig. 17·8

Referring to fig. 17·8, suppose that a vessel is at *X* on the position line *PL*. If a bearing of lighthouse *A* is observed and the position line obtained from the observation is laid down incorrectly to the extent of, say, 10°, the vessel will be erroneously fixed at *Y*. If a bearing of the peak *B* is observed and the resulting position line laid down incorrectly to the same extent, the vessel will be erroneously fixed at *Z*.
Now, although the error in laying down is the same in both cases, the fix obtained from the observation of the nearer object *A* is closer to the vessel's true position than the fix obtained from the more remote peak *B*.

It is interesting to note that an error of 1° in laying down a position line displaces the position line one mile for every 60 miles between the observer and observed mark. For small angles the displacement is roughly proportional to the angular error. This means that an error of 10° produces a displacement of the position line to the extent of about 10 miles for each 60 miles of distance; or 5 miles for each 30 miles of distance, and so on.

The most reliable fix by cross bearings applies when the bearing of two near objects are about 90° apart.

9. Angle of Cut

The angle contained between two position lines is known as the Angle of Cut. The angle of cut should be 90°, or as near to 90° as possible, to ensure a reliable fix, the angle of cut should not be less than about 30°.

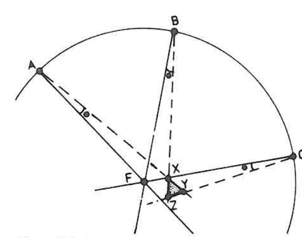


Fig. 17·9

Fig. 17·9 illustrates the effect, of a constant error in laying down three position lines from bearings of three objects which lie at the same distance from a vessel at *F*.

Suppose that the constant error is θ°: using bearings of *A* and *B*, the vessel is erroneously fixed at *X*, using bearings *A* and *C* she is erroneously fixed at *Y*; and using bearings *B* and *C* she is erroneously fixed at *Z*.

Using the three position lines, the cocked hat *XYZ* is formed. It should be noticed that the vessel's true position, in this case, is outside the cocked hat.

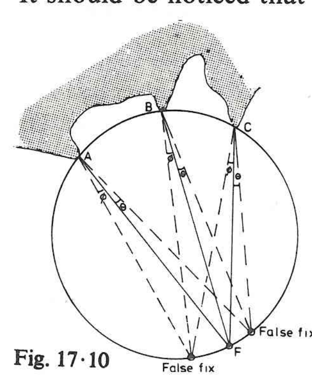


Fig. 17·10

If three position lines intersect at a common point it is reasonable to assume that the vessel has been perfectly fixed. This, in many cases, is a valid assumption; although fig. 17·10 serves to demonstrate that if three position lines obtained from three bearings of objects which lie on the circle which passes through the observer's position as well as through the three objects, are laid down with a constant error, the three position lines will always intersect at a common point. To guard against this possibility objects should be chosen carefully chosen to ensure that the observer does not lie on the circle through the three observed objects.

Exercises on Chapter 17

1. Describe how a position line is obtained from an observation of a shore mark.
2. Describe clearly how a vessel is fixed by cross bearings.
3. What is a check bearing? Explain why, when fixing by cross bearings, a check bearing should be observed when it is possible to do so.
4. What is meant by Angle of Cut? Explain why the angle between position lines should be as near to 90° as possible.
5. Define: Relative Bearing, Transit Bearing.
6. What is a Cocked Hat? Explain how a vessel's position is ascertained when a cocked hat is formed.
7. Explain clearly how a vessel may be fixed from a single bearing and angle.
8. Explain how a vessel may be fixed by a bearing and a sounding.
9. Why should relatively near objects be chosen in preference to more remote objects when fixing cross bearings?
10. Explain how a sector light may be used for fixing.
11. What precautions should be taken when choosing objects for fixing by cross bearings?
12. "When a cocked hat is formed the vessel's true position may lie outside the triangle". Investigate this statement.

CHAPTER 18

THE TRANSFERRED POSITION LINE

1. Introduction

As mentioned in Chapter 17, a vessel cannot be fixed from a single observation. When only a solitary terrestrial object is visible a bearing of that object gives a position line. This single position line has but little value at the time of the observation but, because it may be transferred, it has potential value.

2. Transferring a Position Line

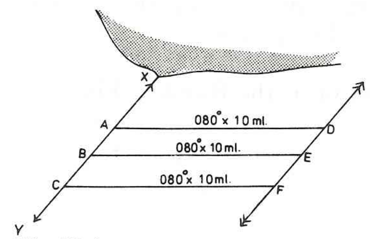


Fig. 18·1

Suppose that the point *X* in fig. 18·1 represents a conspicuous shore mark the bearing of which gives the position line *XY*. The vessel may be fixed somewhere on this line; but, in the absence of additional observational information, it is impossible for a navigator to say where, precisely, his vessel is located on the line. Suppose that immediately after the time at which the observation was made the vessel made good a distance of 10 miles on a course of 080°. Had the vessel been at position *A* at the time of the observation; then, after having made the run, she would have been at *D*. Had the vessel, however, been at *B* at the time of the observation, she would have been at *E* after having made the run. Similarly, had she been at *C* when the observation was made, she would have arrived at *F* after having made the run. It is evident that a straight line may be drawn through the points, *D, E* and *F*, and that this line is parallel to the position line *XY*.

It is clear that, regardless of where the vessel may have been assumed to have been on the position line *XY*, a straight line drawn from the assumed position in a direction 080° at a distance of 10 miles from it, is bound to terminate somewhere on the straight line on which *D, E* and *F*, are located. This is called a Transferred Position Line. To identify it from the original position line it is marked with double arrowheads as indicated in fig. 18·1.

A transferred position line is plotted in the following way: Mark off from any point on the first position line a line to represent the course and distance made good from the time of the observation to that at which the transferred position line is required. Through the end of this line draw a line parallel to the original position line. This is the transferred position line.

The vessel may make more than one course during the interval between the times of an original position line and the transferred position line; and, in many cases, allowance will have to be made for current and/or leeway. But, so long as the courses and current and leeway effects are known with accuracy and that the lines which represent them are laid down carefully, a transferred position line is no less valuable than a position line obtained from observation.

The following example illustrates the use of a transferred position line.

Example 18·1—A navigator on a vessel proceeding up Channel observed Eddystone Lighthouse bearing 020° at 0800 hr. The vessel was travelling at 10 knots on a course of 040°. At 0830 hr. the course was altered to 080°. The current was estimated to be setting 120° at a rate of 3·0 knots. Plot the transferred position line for 0930 hr.

Referring to fig. 18·2: the vessel's position at 0930 hr. is somewhere on the line *XY*.

3. The Running Fix

When it is desired to find a vessel's position at a time when simultaneous observations for cross bearings are not possible, a fix may be obtained as follows:

Two bearings of a single shore mark are observed—the interval of time between the instants at which the bearings are observed being such that the bearing of the mark changes appreciably—more than about 30°—during the interval. If the course and distance made good over the ground in the interval are known, the vessel may be fixed on the second position line at the point where the transferred original position line cuts it.

This method of fixing is known as Fixing by Open Bearings or as the Running Fix.

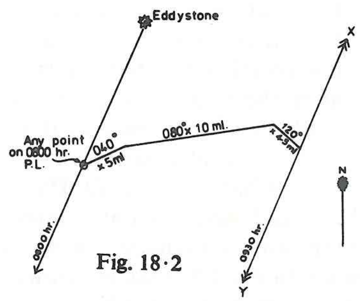


Fig. 18·2

Example 18·2—At 2200 hr. Klein Curaccao Lighthouse bore 305°. The vessel's speed was 12 knots and her course 275°. The current was estimated to be setting at the rate of 2·5 knots in a direction of 230°. Find the distance off the lighthouse when it was abeam at 2300 hr.

From fig. 18·3:

Answer—(By scale drawing) Beam Distance = 9·8 ml.

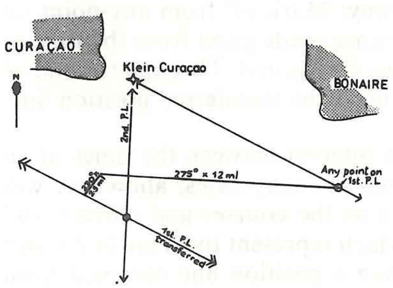


Fig. 18·3

It is not essential, as in Example 18·2, for the second position line to have been obtained from an observation of the object used for obtaining the first position line. It may happen that the bearing of that object did not change sufficiently to give a good angle of cut during the interval during which it was within range of visibility. In this case a second object may be observed, and a position line obtained from it, when crossed with the original position line transferred, enables the navigator to fix his vessel.

Example 18·3—Point *A* bore 265° at 0800 hr. The vessel travelled for 18·0 ml. on a course of 355°, during which time the current set 340° for 5·0 ml. At the end of the run Point *B*, located 30·0 ml. due North of Point *A*, bore 324°. Find the distance from Point *B* at the time of the second observation.

Referring to fig. 18·4:

Answer—(By scale drawing) Distance = 7·8 ml.

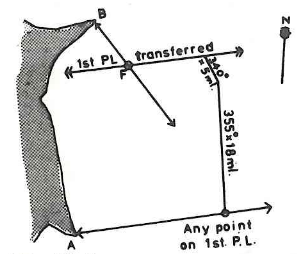


Fig. 18·4

It must be borne in mind that to obtain an accurate position using the Running Fix method, the course and distance made good over the ground during the interval between the times at which the first and second observations were made must be known with certainty. It follows that, because these effects cannot be known exactly, the running fix method should not be used when a cross bearing fix is possible. Of course, when prominent shore marks are not available, the navigator has no alternative but to use a running fix, but such should not be relied upon implicitly, especially when knowledge of currents or tidal streams is uncertain, or when the weather is rough and the effect of wind is uncertain.

4. Additional Use of a Position Line

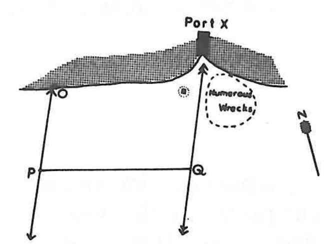


Fig. 18·5

Suppose a vessel is travelling off the coastline illustrated in fig. 18·5, and that she is bound for the Port *X*. Suppose that the approach course to the port is 024°—a direction that can be measured from the chart before the vessel arrives off the port. If the time at which the conspicuous object *O* is bearing 024° is noted, and if the time taken for the vessel to make good a distance equal to *PQ* is calculated; then, after the interval of time that elapses from the time of the observation if the vessel's course is altered to 024°, she will make the Port *X* irrespective of her position on the transferred position line illustrated in fig. 18·5.

This wrinkle is particularly useful in cases when the weather might become thick, or in cases in which coast and harbour are not well lighted or marked.

5. Doubling the Angle on the Bow

If the relative bearing of a shore mark is observed, provided that it is less than 45°, the distace run between the time of the observation and that at which the relative bearing has doubled, is equal to the distance off the mark at the time of the second observation. This applies only when the vessel has not been affected by current or wind during the interval.

Fig. 18·6 illustrates the principle of the method described above—a method known as Doubling the Angle on the Bow.

Referring to fig. 18·6:

If $CBX = 2CAB$
Then $ACB = CAB$ and the triangle ABC is isosceles
Therefore: $AB = BC$
Or: Distance run = Distance off at Second Observation

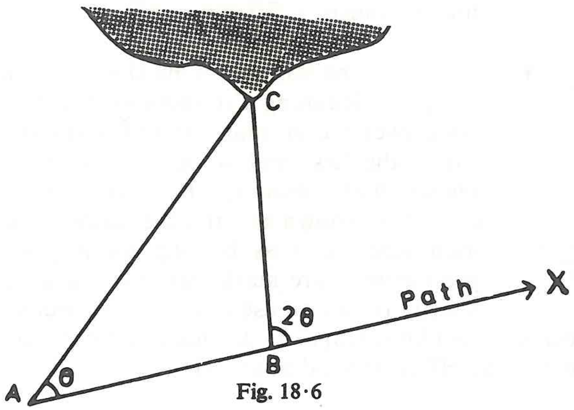


Fig. 18·6

If the angle θ in fig. 18·6 is equal to 45° the distance run is equal to the beam distance when the relative bearing has doubled. This method of finding the beam distance is known as the Four Point Bearing Problem. It does not give accurate results when current and/or leeway influence the progress of the vessel.

6. The Four Point Bearing Problem with Leeway and Current

The beam distance off a shore mark may be found by transferring a position line obtained from an observation of the shore mark made at the time it was four points on the bow, and crossing it with the position line obtained from a beam bearing observation. It may also be computed using plane trigonometry. The traverse table is used to facilitate this problem: a diagram also assists in the solution.

In the trigonometrical method of solving the four point bearing problem with current and leeway it is necessary to find four quantities, these being the unknown sides of two right-angled triangles. One of these triangles has for its hypotenuse the distance travelled by the vessel in the interval between the four point and beam bearings; and the other has for its hypotenuse the drift of the current in the interval.

The folowing examples, although only of slight practical importance, are useful in the understanding of the problem as well as affording practice at using the Traverse Table.

Example 18·4—At 0200 hr. from a vessel heading 080°, a conspicuous tower P was observed to bear 45° on the port bow. At 0300 hr. it bore abeam. The vessel logged 8·0 ml. in the interval. The leeway due to a North wind was 10°, and the current was setting 140° at 4·0 knots. Find the distance off the tower at 0300 hr.

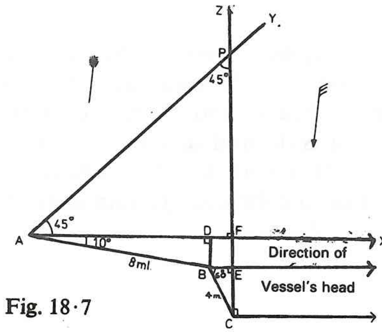


Fig. 18·7

Referring to fig. 18·7: Let A be the vessel's position at 0200 hr. Draw AX in a direction 080°. Construct an angle of 45° at A and draw AY. P must lie on AY. Construct the angle of leeway, that is, 10°, at A, and draw AB to represent 8·0 ml. The point would be the vessel's position had there been no current. Draw BC in the direction of the set and of distance equal to the drift of the current, that is, 4·0 ml. At positions B and C draw lines parallel to AX, the direction in which the vessel is heading. Draw CZ at right angles to the vessel's heading. Denote the point of intersection of AY and CZ by P. Draw BD parallel to CZ.

Solution—Using Traverse Table: find AD, BD, BE and CE.

$$\begin{aligned}
\text{Beam Distance} &= PC\\
&= PF + FC\\
&= AF + FC\\
&= (AD + DF) + (CE + EF)\\
&= (AD + BE) + (CE + BD)\\
AD &= 7{\cdot}9\\
BE &= 2{\cdot}0\\
CE &= 3{\cdot}5\\
BD &= 1{\cdot}4\\
PC &= 14{\cdot}8
\end{aligned}$$

Answer—Beam Distance = 14·8 ml.

Example 18·5—From a vessel heading 170° Point P is observed to be 45° on the starboard bow. After travelling for 30 minutes at 12·0 knots, during which time the current set 040° at a rate of 4·0 knots, and the leeway due to a West wind was 10°, the point was abeam. Find the beam distance.

Referring to fig. 18·8:

Find by Traverse Table: AB, BC, CD and DE.

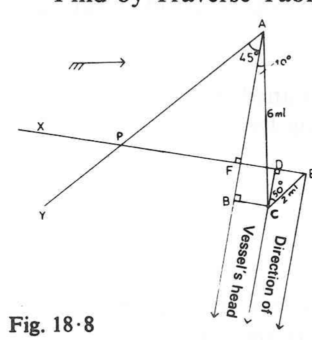


Fig. 18·8

$$\begin{aligned}
\text{Beam Distance} &= PE\\
&= PE + EF\\
&= (AB - CD) + (BC + DE)\\
AB &= 5{\cdot}9\\
CD &= 1{\cdot}3\\
&\ 4{\cdot}6\\
BC &= 1{\cdot}0\\
DE &= 1{\cdot}5\\
PE &= 7{\cdot}1
\end{aligned}$$

Answer—Beam Distance = 7·1 ml.

7. Special Angles

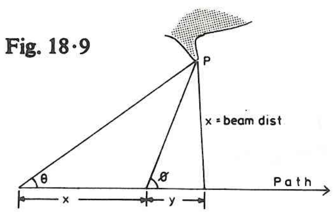
The Four Point Bearing method of finding the beam distance, regardless of whether wind and/or current affect the progress of the vessel, suffers from the disadvantage that the required distance is not known until the vessel is actually abeam, and therefore at the position of greatest danger relative to the observed point. If it is desired to know the beam distance before the vessel is at its nearest approach to the point, resort may be made to the use of Special Angles. These are two relative bearings such that the distance run on a steady course between the times of observations is equal to the beam distance.

In fig. 18·9, θ and φ are Special Angles.

It may readily be proved that the cotangents of Special Angles differ by unity.

Referring to fig. 18·9:

Fig. 18·9



$$\text{Cot } \theta = (x+y)/x$$
$$\text{Cot } \theta = y/x$$
$$\text{Cot } \theta - \text{cot } \theta = (x+y)/x - y/x$$
$$= (x+y - y)/x$$
$$= 1$$

Thus, if θ is, say, equal to 25°, φ must be 34¾°. The angles 25° and 34¼° are, therefore, special angles because their cotangents differ by unity.

$$\cot 25° = 2{\cdot}14451$$
$$\cot 34\tfrac{3}{4}° = 1{\cdot}14451$$
$$\cot 25° - \cot 34\tfrac{3}{4}° = 1{\cdot}00000$$

The most useful pair of special angles are 26½° and 45°. This follows because the distance run by the vessel between the times of the observations is equal to the distance to run to bring the point abeam, as well as being equal to the beam distance.

When a shore mark is fine on the bow its relative bearing changes comparatively slowly. therefore, when using special angles, the relative bearing at the first observation should not be too fine on the bow.

It cannot be too strongly emphasized that the beam distance obtained from this method is accurate only when there is no current and the vessel is not making leeway.

Exercises on Chapter 18

1. Explain clearly how a position line is transferred.
2. Explain how a single position line may be used to make harbour when fog sets in.
3. What are the advantages and disadvantages of the Running Fix method?
4. Explain the principle of Doubling the Angle on the Bow.

5. What are Special Angles? Prove that special angles are those whose cotagents differ by unity.
6. At 1000 hr. Start Point in Lat. 50° 13′ N. Long. 03° 38′ W. bore 020°. After travelling for one hour at 12·0 knots on a course of 080°, in a current setting 290° at 2·0 knots, Start Point bore 342°. Find by scale drawing the distance off the point at 1100 hr.
7. Sombrero Light in Lat. 18° 36′ N. Long. 63° 28′ W. bore 258°. After travelling for a distance of 6·0 ml. on a course of 185°, and 5·0 ml. on 210°, it bore 346°. Find the distance off and the latitude and longitude of the vessel at the time of the second observation.
8. Ascension Island in Lat. 07° 57′ S. Long. 14° 21′ W. bore 260°. After travelling for 20 ml. on a course of 185° it bore 320°. Find the distance off at each of the times of observation.
9. At 0700 hr. Flamborough Head in Lat. 54° 07′ N. Long. 00° 05′ W. bore 320° (C). The vessel's course was 350° (C). Variation = 13° W. Deviation 3° E. At 0800 hr. the light bore 255° (C). Find the vessel's position at the time of the first observation given that the speed through the water was 8·0 knots and the current was setting 180° at a rate of 2·5 knots. Find also the distance off the light at 0800 hr.
10. Heading 082° at 12·0 knots Point *A* bore 4 points on the port bow. After travelling for 45 minutes it was abeam. Find the distance off at the time of the second observation given that the current was 135° at 4·0 knots, and the leeway due to a North wind was 10°.
11. Heading 086° (C). Variation 5° 0′ E., Deviation 6° 0′ E., the Fastnet Rock in Lat. 51° 23′ N. Long. 09° 36′ W. bore 45° on the port bow. After travelling for 1 hr. 20 m. it was abeam. Find the beam distance given that the vessel's speed through the water was 7·0 knots; the current was 200° at 4·0 knots; and the leeway due to a North wind was 5°.
12. Heading 172° at 16·0 knots a lighthouse bore 45° on the starboard bow. 30 minutes later it was abeam. Find the beam distance if the current has been setting 100° at 4·0 knots and the leeway due to an East wind has been 10°.
13. A point of land bore 22° on the port bow. 25 minutes later it bore 44° on the port bow. Find the distance off the point when it is abeam given that the vessel's speed is 12·0 knots and that there is no current or wind.
14. Heading 222° (C). Compass Error 10° E. Speed 10·0 knots through the water. A point of land bore 45° on the starboard bow. The point was abeam 45 minutes later. Find the beam distance assuming that the current has been setting 265° at 4·0 knots and the leeway due to a North wind had been 5°.
15. Heading 330° at 15·0 knots a light vessel bore 015°. 40 minutes later it was abeam. Find the distance off at the time of the second observation given that the current was 000° at 6·0 knots and the leeway due to an East wind had been 10°.

CHAPTER 19

POSTION LINE BY VERTICAL ANGLE: DISTANCE OF THE HORIZON

1. Distance off by Vertical Angle

If the vertical angle subtended by an object of known height above sea level is measured by means of a sextant; then, provided that the base of the object is within the visible horizon of the observer, the distance off may be found trigonometrically, on the assumption that the vertical height of object and the horizontal distance off form two adjacent sides of a right-angled plane triangle. This is illustrated in fig. 19·1.

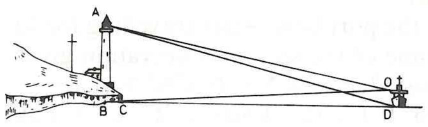


Fig. 19·1

If the distance BD in fig. 19·1 is large in comparision with distances BC and OD, the angle AOC is very nearly equal to the angle ADB, and it may be used instead of ADB for finding BD—without introducing material error.

If the Vertical sextant Angle (V.S.A.) of a lighthouse or other vertical object is θ, and the height of the top of the vertical object above sea level is h feet, the distance off in nautical miles is given by the formula:

$$\text{Distance off} = (h \cot \theta)/6080$$

if h is given in metres, the corresponding formula is:

$$\text{Distance off} = (h \cot \theta)/1852$$

It is not necessary ever to compute a problem in which the distance off an object of known angular height is to be found: most collections of Nautical Tables include a table designed to give the answers by inspection.

It must be remembered that the charted height of a lighthouse is the vertical distance from the level of M.H.W.S. to that of the centre of the lens of the light. Great care, therefore, is necessary when measuring the vertical angle of a lighthouse. The telescope of highest magnification available should be used, and an allowance should be made for the state of the tide, if an accurate and reliable result is expected. Quite often H.W. level is distinctly visible as a dark tide mark on rocky shores, or it may be identified by a line of stranded flotsam. If this is so the angle between the direction of the centre of the lens and that of the H.W. mark vertically below it should be measured. It is useful to note that if no allowance is made for the state of the tide, the calculated distance off will be less than the actual distance.

If the distance off a charted mark is known, a circular position line may be determined. With distance off as radius centred at the chartered position of the mark, the resulting arc of the circle is a line somewhere on which the vessel's position may be fixed. Such a line is a

position line; or more strictly in this case, a position circle. It is useful to remember that when it is necessary to transfer a position circle, the simplest method is to transfer the centre and to draw the transferred position circle centred at the transferred centre.

The distance off determined from a V.S.A. observation may be found by means of a neat little formula which has the advantage over that given above in that no trigonometrical tables are required in its use. This formula is derived with reference to fig. 19·2.

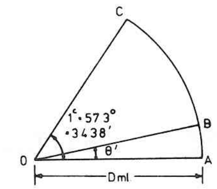


Fig. 19·2

A knowledge of circular measure and the use of radians is essential for a clear understanding of the formula now to be derived. The reader is referred to Chapter 2.

From fig. 19·2:

$$\frac{\text{Arc } AC}{\text{Radius } OA} = 1 \text{ (because } COA = 1 \text{ radian)}$$

$$\frac{\text{Arc } AB}{\text{Chord } AB} = 1 \text{ very nearly (because } \theta \text{ is a small angle)}$$

Thus: $$\frac{\text{Arc } AC}{\text{Radius } OA} = \frac{\text{Arc } AB}{\text{Chord } AB}$$

and: $$\frac{\text{Arc } AC}{\text{Arc } AB} = \frac{\text{Radius } AO}{\text{Chord } AB}$$

That is: $$\frac{COA}{AOB} = \frac{D}{h}$$

or: $$\frac{3438}{\theta'} = \frac{D}{h}$$

Thus: $$D\,(\text{in ml.}) = \frac{h' \,.\, 3438}{\theta' \,.\, 6080} \quad (h \text{ in ft.}) \quad \ldots\ldots \quad \text{(I)}$$

Or: $$D\,(\text{in ml.}) = \frac{h' \,.\, 3438}{\theta' \,.\, 1852} \quad (h \text{ in metres}) \quad \ldots\ldots \quad \text{(II)}$$

Formulae I and II reduce, respectively, to:

$$D\,(\text{in ml.}) = 0{\cdot}565\ h/\theta$$

and $$D\,(\text{in ml.}) = 1{\cdot}856\ h/\theta$$

The formula giving distance off in terms of height of object and Vertical Angle may be transposed to give V.A. in terms of D and h. The angle θ may be required when it is desired to set the sextant with the angle θ corresponding to the least safe distance to pass a lighthouse. The angle, when used in this way, is called a Vertical Danger Angle (V.D.A.).

The use of a V.D.A. facilitates the process of rounding a headland when the nearest approach to a lighthouse located on the headland is to be not less than a given distance on account of the existence of some off-lying danger

By transposition:

$$\theta = \frac{h}{D} \cdot 0{\cdot}565 \qquad (h \text{ in feet})$$

or:

$$\theta = \frac{h}{D} \cdot 1{\cdot}856 \qquad (h \text{ in metres})$$

2. Distance of the Theoretical Horizon

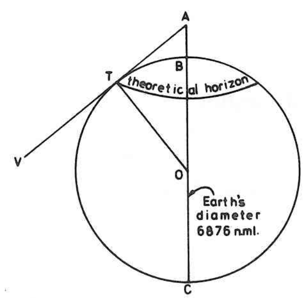


Fig. 19·3

Ignoring the effect of atmospheric refraction, the range of the theoretical horizon, as illustrated in fig. 19·3, is *BT* where *T* is the tangential point on the line *AV*.

Because the height of an observer's eye is usually small compared with the distance of the visible horizon. *AT* is so nearly equal to *BT* that no apperciable error is introduced by assuming that *AT* is equal to *BT*.

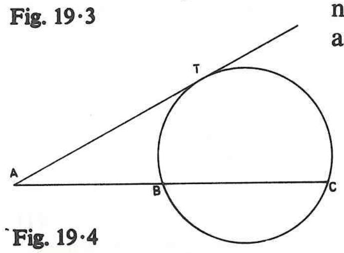


Fig. 19·4

The line *AT* in fig. 19·4 is a tangent to the circle, and the line *ABC*, which cuts the circle at any points *B* and *C*, is a secant. It may be proved that for any tangent *AT* and any secant *AC*:

$$AT^2 = AB \cdot AC$$

From this proposition, and referring back to fig. 19·3:

$$AT^2 = AB \cdot AC$$

Therefore:

$$BT^2 = AB \cdot AC$$

and

$$BT = \sqrt{AB \cdot AC}$$

But *AB* is so very small compared with *BC* that *AC* may be treated for all practical purposes as being equal to the Earth's diameter.

Therefore

$$BT = \sqrt{AB \cdot BC}$$

$$= \sqrt{\text{Ht. of Observer's eye} \cdot \text{Earth's diameter}}$$

$$= \sqrt{\frac{\text{Ht. in feet} \cdot 6876}{6080}}$$

$$\sqrt{1{\cdot}13 \cdot h}$$

$$= 1{\cdot}06\,\sqrt{h}$$

Thus:

Distance of Theoretical Horizon ($D = 1{\cdot}06\,\sqrt{h}$ where (D) is in nautical miles and h, the height of the observer's eye above sea level, is in feet.

If h is given in metres instead of feet, the corresponding formula is:

$$D \text{ (in nautical miles)} = 1{\cdot}93\,\sqrt{h \text{ (in metres)}}$$

The effect of normal atmospheric refraction is for an observer's actual, or Visible, horizon to lie at a greater distance than that of his theoretical horizon.

Making allowance for the effect of normal refraction, the distance of the Visible Horizon is about one-twelfth of the distance of the theoretical horizon beyond the theoretical horizon. Thus the distance of the visible horizon is given by the formula:

$$\text{Distance (in ml.)} = 1{\cdot}15\,\sqrt{h} \text{ (in feet)}$$

or:

$$\text{Distance (in ml.)} = 2{\cdot}09\,\sqrt{h} \text{ (in metres)}$$

This formula is useful for finding the extreme distance at which at light of known height is just visible.

When a vessel is approaching a lighthouse at night the distance off the light at which it heaves into view is known as the Rising Range. When travelling away from a light, the range at which it disappears is known as the Dipping Range. The dipping or rising range depends upon the heights of the light and of the observer's eye above sea level. It also depends upon the state of the tide.

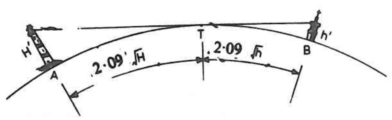


Fig. 19·5

Fig. 19·5 illustrates how the extreme range of a light is found.

The extreme range of the light illustrated in fig. 19·5 may be found by adding the distance AT to that of BT.

$$\text{Extreme range} = 2{\cdot}09\ \sqrt{h} + 2{\cdot}09\ \sqrt{H}$$

$$= 2{\cdot}09\,(\sqrt{h} + \sqrt{H}) \quad (h \text{ in metres})$$

Example 19·1—Find the extreme range of a light whose height above sea level is 100 metres, if the observer's eye is 49 m. above sea level.

$$\text{Distance} = 2{\cdot}09\ (\sqrt{49} + \sqrt{100})$$

$$= 2{\cdot}09\ (7 + 10)$$

$$= 2{\cdot}09\ (17)$$

$$= 35{\cdot}53 \text{ ml.}$$

Answer—Distance = 35·53 miles.

Metric charts give the Nominal range, which presumes a visibility of only 10 miles, and takes into account of light intensity only, in clear weather, and ignoring the height of the observer's eye. The observer must therefore check that the luminous range is capable of being achieved, as limited by Geographical range.

Geographical range is the maximum distance at which a light can theoretically reach an observer. It is limited only by the curvature of the earth and the refraction of the atmosphere, and by the elevation of the light and height of eye of the observer.

Great care should be exercised when using a distance off found from an observation of a dipping or rising light. Atmospheric conditions sometimes exist which cause lights to be seen at sometimes a greater, and sometimes a less, range than the theoretically rising or dipping range. When these conditions exist atmospheric refraction is said to be Abnormal. When abnormal refraction is suspected a position obtained by this method should be treated as suspect.

Quite frequently when approaching it a light flashed at a lighthouse is seen by reflection from clouds, or even from the atmosphere itself, before the direct rays of the light are visible. When this is so the light is said to be looming or to loom. To ascertain the bearing of a looming light a star which has the same bearing as the light should be sought, and a bearing of the star instead of that of a point on the horizon vertically below, should be observed.

Exercises on Chapter 19

1. Explain in detail how a Vertical Sextant Angle of a lighthouse should be observed. How

is a position line obtained from a V.S.A. observation, and how is such a position line transferred?

2. Explain the derivation of the formula: $D = 1{\cdot}93\ \sqrt{h}$, where D is the range of the theoretical horizon in nautical miles and h is the height of the observer's eye in metres.
3. What is the effect of atmospheric refraction on the range of the horizon? What is the formula used for finding the range of the visible horizon?
4. What is meant by abnormal refraction?
5. What is meant by looming?
6. Find the distance off a lighthouse of height 37 m. above sea level, if the V.S.A. is 2° 15′·0. Explain why the observer's own height of eye does not enter the problem?
7. Explain how the dipping range of a light may be found?
8. Find the extreme range of a light of height 49 m. above sea level to an observer whose height of eye is 20 m.?
9. Explain the use of a Vertical Danger Angle.
10. Find the V.D.A. when it is necessary to pass not less than 2·5 ml. from a lighthouse of height 100 m.
11. Prove that if AX is a tangent to a circle at T, and AY is a secant to the same circle cutting it at B and C respectively, $AT^2 = AB \,.\, AC$.

CHAPTER 20

POSITION LINE BY HORIZONTAL ANGLE

1. Geometrical Principles

A locus line in geometry is a line every point on which conforms to a given set of conditions. The locus line of points at which the angle between the directions of the two extremities of a straight line is a constant, for example, is the arc of a circle of which the straight line is a chord.

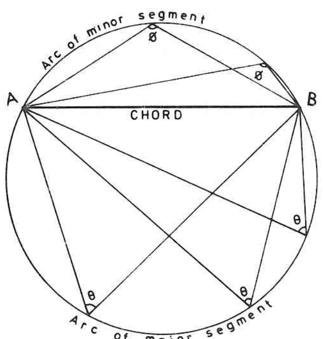


Fig. 20·1

Let AB in fig 20·1 be any straight line. If a circle is drawn such that AB is a chord of the circle: then, at every point on the arc of the major segment the angle between the directions of A and B from the point is θ. Similarly at any point on the arc of the major segment the angle between the directions of A and B is φ.

The values of θ and φ depend on the position of the chord with respect to that of the centre of the circle. This is illustrated in fig. 20·2.

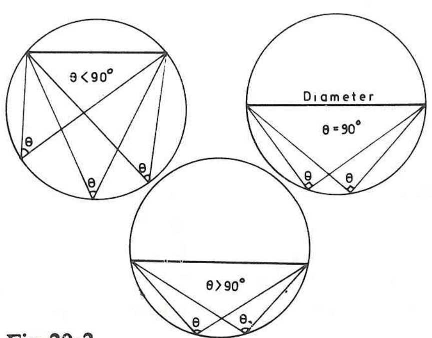


Fig. 20·2

In will be seen in fig. 20·2 that the nearer is the chord to the centre of the circle the greater is the value of θ and the smaller is the value of φ. If the angle between the extremities of the chord is less than 90° the point at which the angle is measured is on the arc of the major segment. If the angle is greater than 90° the point lies on the arc of the minor segment. If the angle is exactly 90° the point lies on the arc of a semicircle, and the chord, in this case, is a diameter.

Another important geometrical proposition is that the angle at the centre of a circle standing on a chord is double the angle standing on the same chord at the circumference. This is illustrated in fig. 20·3.

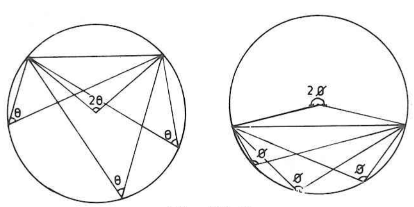


Fig. 20·3

2. Application to Fixing

Suppose the horizontal angle between two shore marks is measured. From this information a navigator knows that his vessel lies on the arc of a circle on which the two observed marks lie. Such an arc, when drawn on a chart, is a position line or, more precisely a Position Circle. The process of plotting a position circle obtained from an horizontal angle observation is as follows:

The charted positions of the observed marks are connected with a straight line. This is a chord of the required position circle. If the measured angle is less than 90° the position line is an arc of a major segment of the circle. If the measured angle is greater than 90° it is an arc of a minor segment, and if the measured angle is 90°, the position line is a semicircle.

When the position line is an arc of a major segment the centre of the required circle and the vessel lie on the same side of the chord. When the position line is an arc of a minor segment the centre of the circle and the vessel lie on opposite sides of the chord. When the measured angle is exactly 90° the centre of the position circle lies at the mid-point of the straight line joining the charted positions of the two observed marks.

The centre of the position circle lies at the apex of an isosceles triangle which has for its base the chord of the circle, or line joining the charted positions of the observed marks. The equal angles of this triangle are each ½(180° − 2 θ) where θ is the measured angle. This may be verified from fig. 20·4.

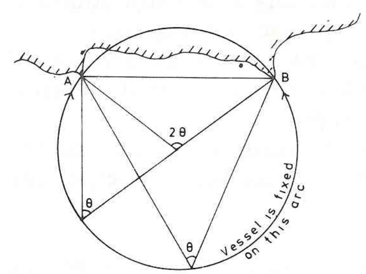


Fig. 20·4

Referring to fig. 20·4, which illustrates the case in which the measured angle is less than 90°, if the measured angle is θ, and A and B represent the observed marks, the angle at the centre of the position circle is equal to 2 θ. Hence the angles BAO and ABO are each equal to ½(180° − 2 θ). This follows because the sum of the angles in any plane triangle is equal to 180°.

Now: $\frac{1}{2}(180° - 2\theta) = (90° - \theta)$

Therefore: the angle to construct on the seaward side of the line joining the charted positions of the marks is the complement of the measured angle.

Referring to fig. 20·5, which illustrates the case in which the measured angle is more than 90°, if the measured angle is φ and the two marks denoted by A and B, the reflex angle at O, the centre of the required position circle, is equal to 2 φ.

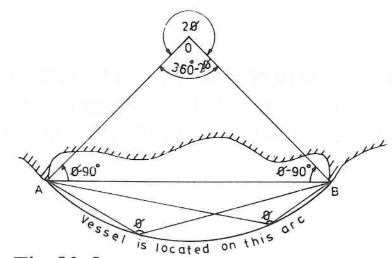


Fig. 20·5

$$
\begin{aligned}
\text{Therefore:} \quad AOB &= 360° - 2\varphi \\
\text{and} \quad OAB = OBA &= \tfrac{1}{2}(180° - [360° - 2\varphi]) \\
&= \tfrac{1}{2}(180° - 360° + 2\varphi) \\
&= \tfrac{1}{2}(2\varphi - 180°) \\
&= \varphi - 90°
\end{aligned}
$$

Therefore: the angle to construct at A and B is equal to the excess of the measured angle over 90°, and this angle is to be constructed on the landward side of the chord AB.

3. The Horizontal Danger Angle

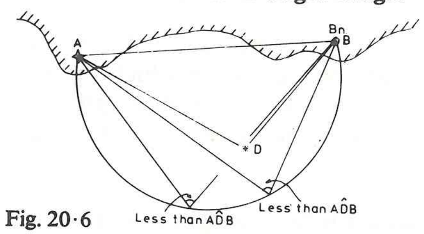


Fig. 20·6

Referring to fig. 20·6, suppose a danger *D* lies offshore in the vicinity of two well-marked objects *A* and *B*. A navigator in passing *D* has only to ensure that the horizontal angle between the objects *A* and *B* does not exceed the angle *ADB*, which is measured in advance from the chart. If such be the case, the vessel will pass clear and outside of the danger. The angle at the danger between the two shore objects is referred to as a Horizontal Danger Angle (H.D.A.). The angle to set on the sextant should be smaller than the H.D.A. to ensure a safe clearance.

4. Fixing by Horizontal Angles

If two horizontal angles are measure and two intersecting position circles plotted, the vessel is fixed at one of the intersection points of the two circles. If three marks are observed from which two circles are obtained, one of the intersections lies at one of the observed marks, so that there is no ambiguity in fixing. This method of fixing a vessel has great value and is sometimes preferable to every other available method. The main reasons for this are:

(i) A reliable fix may be obtained even when the compass error is not known. The method, therefore, is extremely useful for fixing a vessel at anchor or for rapid continuous fixing when navigating narrow and tortuous channels when course is frequently being altered, and residual deviations may be large and uncertain.

(ii) When the distance between the vessel and the observed marks is great the necessity of drawing long lines on the chart when fixing by cross bearings may introduce error. Fixing by horizonatal angles, in these circumstances, is preferable.

(iii) The method is particularly valuable at times when the vessel is rolling and the compass, as a consequence, unsteady. In such cases compass bearings, especially when observed with a magnetic compass, are unreliable.

Although for convenience and accuracy the sextant is usually employed for measuring horizontal angles, the angle may be measured using the Standard Compass—provided that the card is steady. Fixing a vessel using angles measured with a compass, allows the navigator to check the compass error for the particular heading of the vessel at the time of the observation. Having fixed the vessel it then remains to find the true bearing of one of the observed marks and to compare this with its corresponding compass bearing: the difference being the compass error.

The required horizontal angles may be found from relative bearings. For example, it may be observed that one mark is dead ahead at the same time as another is abeam. The horizontal angle between the marks is, therefore, 90°, and the vessel may be fixed on the semicircle of which the line joining the marks is a diameter.

5. Reliability of the Horizontal Angle Fix

There are two main factors to consider in relation to the reliability of a fix obtained from horizontal angles. These are:

(i) The Angle of Cut: this should be as near to 90° as possible for a reliable fix. In some instances it is advisable to draw three circles, the third being the circle which passes through the two outer marks. Example 20·5 illustrates a typical case in which the three circles should be drawn.

(ii) Care necessary to ensure that the three marks and the ship are non-cyclic. If the three marks and the observer lie on the same circle the two position circles are coincident and a fix is impossible in these circumstances.

6. Method of Recording a Fix by Horizontal Angles

If the horizontal angle between points *A* and *B* is, say θ; and that between *B* and *C* is φ, the observation is recorded thus: *a* θ *B* φ *C* in which *B* lies to the right of *A*, and *C* lies to the right of *B*.

7. Examples of Fixes by Horizontal Angles

The following examples indicate the usefulness of the method of fixing by horizontal angles.

Example 20·1—The horizontal sextant angle between point *A* and steeple *B* was 70° at the same time as the steeple was in transit with peak *C*. Fix the vessel.

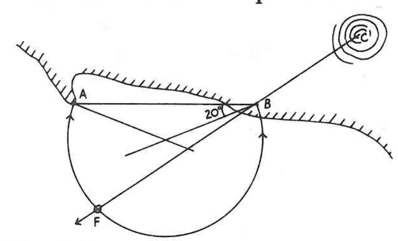


Fig. 20·7

Referring to fig. 20·7:

Vessel is fixed at F

N.B.—The keen and expert navigator is always on the lookout for suitable transit marks when coasting.

Example 20·2—Light vessel *A* 60° Buoy *B* 100° Point *C*. Fix the vessel.

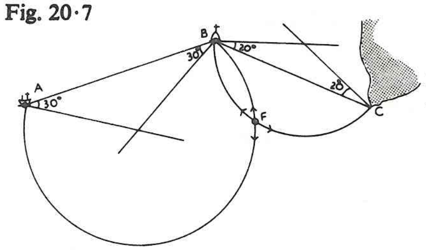
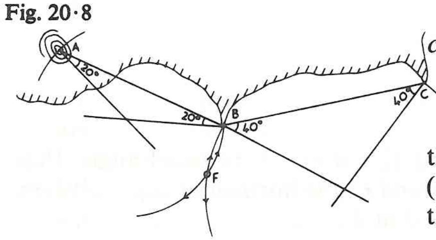


Fig. 20·8

Referring to fig. 20·8:

Vessel is fixed at the intersection of the two position circles



Example 20·3—Peak *A* bore 010° (C) at the same time as point *B* bore 080° (C) and Chimney *C* bore 130° (C). Fix the vessel and ascertain the compass error for the vessel's heading at the time of the observation.

Referring to fig. 20·9:

Vessel is fixed at F

True Bearing of A (from chart) = 340°
Compass Bearing of A = 010°

Compass Error = 30° W.

Example 20·4—Buoy A was right ahead, Light vessel B was on the starboard beam, and Buoy C was 4 points abaft the starboard beam. Fix the vessel.

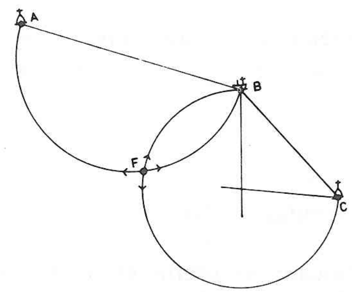


Fig. 20·10

Referring to fig. 20·10:

A 90° B 45° C

Vessel is fixed at F

Example 20·5—Point A 20° Point B 30° Point C. Fix the vessel.

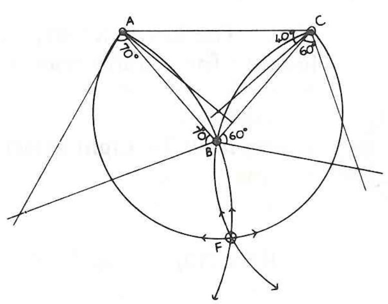


Fig. 20·11

Referring to fig. 20·11:

Vessel is fixed at F

N.B.—The circles through A and B, and through B and C, cut at a very small angle, thus giving an unreliable fix. By drawing the circle through A and C, the horizontal angle between which is (20+ 30)° that is, 50°, the vessel is reliably fixed at F.

8. Use of Tracing Paper for Fixing by Horizontal Angles

To obviate the need for cluttering the chart with geometrical construction lines, as we have done in the preceding examples, the measured angles may be drawn from a common point on a large sheet of transparent paper. If the paper is then placed on the chart and moved about until the arms of the angles coincide with the charted positions of the observed marks, the vessel may be fixed without drawing any lines on the chart. The fix is located immediately under the point of intersection of the three lines, and may be transferred to the chart with the aid of a point of a dividers.

9. The Station Pointer

A very useful instrument, the principle of which is based on the geometry given above, is the Station Pointer. The station pointer consists of a transparent disc graduated in degrees from 0° to 180° to the right and left. Three radial arms are centred at the centre of the disc; the middle one being fixed and the outer ones moveable. The bevelled edge of the fixed arm coincides with the zero graduation mark on the circumference of the disc. The two moveable arms are capable of being clamped at angles equivalent to those measured by means of a sextant or compass. After setting the instrument, having been careful to set the right-hand arm to the angle between the centre and right-hand mark, and the left-hand arm to the angle between the centre and left-hand mark; the instrument is placed on the chart and adjusted so that the bevelled edges of the three arms coincide, respectively, with the charted positions of the three marks. The vessel is then fixed: a hole at the centre of the disc, having a diameter equal to that of a pencil, facilitating the marking of the chart.

Great caution is necessary when using tracing paper or station pointer for fixing by horizontal angles. Neither device provides an indication of angle of cut, and hence the degree of reliability of the resulting fix. The following rules should be observed when choosing marks for fixing by horizontal angles.

(i) Choose marks which lie more or less on the same straight line; or:
(ii) Choose marks such that the middle one is the nearest one to the observer; or:
(iii) Choose marks such that the vessel lies within the triangle formed by the three marks. By doing so the navigator will ensure that his fix is reliable.

When a vessel is making headway, and it is desired to fix by means of horizontal sextant angles, it is essential that the angles are measured simultaneously. Especially is this important when the vessel's speed is great and the distance offshore is relatively short.

Navigating tricky channels by horizontal sextant angles is a three-man job. Two observers should be employed in measuring the angles simultaneously, and a third should attend to the plotting of the angles on the chart.

Exercises on Chapter 20

1. Explain the principles of obtaining a position line from an observation of a horizontal angle between two charted marks.
2. What precautions are necessary when fixing by horizontal angles?
3. What are the advantages and disadvantages of fixing by horizontal angles compared with fixing by cross bearings?

4. Explain how the compass error may be checked using horizontal compass bearings.
5. What rules should a navigator observe when choosing marks for fixing by horizontal angles?
6. Describe a station pointer and explain how it is used.
7. Prove that, if three shore marks and a vessel lie on the same circle, a fix by horizontal angles is impossible. Hence show the danger of using a station pointer carelessly.
8. Lighthouse *Y* bears 100° (T) distance 3·0 ml. from a steeple *X*. A conspicuous chimney *Z* lies 065° (T) distance 6·0 ml. from the lighthouse. A vessel to the southwards observes *X* to bear 310° (C) at the same time as *Z* bears 025° (C) and *Y* bears 325° (C). Find the distance of the vessel from *Y* and the compass error for the heading of the vessel at the time of the observation.
9. *B* is 086° (T) distance 6·0 ml. from *A*. *C* is 095° (T) distance 5·0 ml. from *B*. *A* vessel to the northwards makes the following observations:

   A 48° *B* 67° *C*

   Find the distance between the vessel and *B* at the time of the observations.
10. A buoy *A* lies 330° (T) distance 5·0 ml. from a buoy *B*. Buoy *C* lies 265° (T) distance 4·5 ml. from *B*. A vessel at anchor observes the H.S.A.'s between *A* and *B*, and between *B* and *C*, to be 110° and 105° respectively. Find the bearing and distance of the nearest buoy.
11. Point *A*, which lies to the westward of a vessel, was abeam to port at the same time as Point *B* was dead astern. The horizontal angle between *B* and *C* was 10°. *B* is due South (T) of *A* at a distance of 5·0 ml., and *C* is 200° (T) distance 7·0 ml. from *A*. Find the distance of the vessel from *B*.
12. *A* is 5·0 ml. 330° (T) from lighthouse *B*, the height of which is 150 ft. above sea level. The V.S.A. of *B* is 30′ 00″. Find the distance of the vessel from *A* if the H.S.A. between *A* and *B* is 50°.

CHAPTER 21

THE THREE BEARING PROBLEM

1. Principles

If three bearings of a fixed shore mark are observed and the distances run through the water between the times of taking the first and second, and the second and third observations, are known; then, if the observer's vessel has maintained a steady course and speed in the interval, the True Course made good, that is to say, the course made over the ground, may readily be ascertained.

If, instead of the distances travelled, the intervals that elapse between the instants of the observations are known, the same result may be obtained. This follows because distances travelled by a vessel making a uniform speed are proportional to the times taken to make these distances. This principle, simple and useful as it is, seems not to be employed as much as it should be.

The principle is based on the properties of similar triangles. Similar triangles are those which are equi-angular.

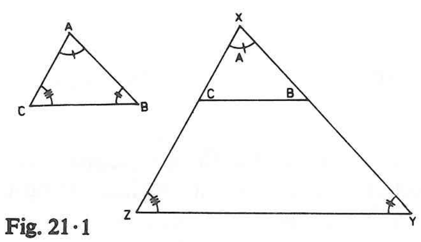


Fig. 21·1

The two triangles *ABc* and *XYZ* illustrated in fig. 21·1 are similar triangles. An important property of similar triangles is that the ratio between corresponding sides is constant. Referring to the triangles illustrated in fig. 21·1, we have:

$$AB : XY : : AC : XZ : : BC : YZ$$

or: $$AB/XY = AC/XZ = BC/YZ$$

Notice the the triangle *ABC* fits exactly into the corner of triangle *XYZ*, and that when so fitted the side *BC* of the triangle *ABC* is parallel to the side *YZ* of the triangle *XYZ*. So that:

$$XB/XY = BC/YZ = XC/XZ$$

2. Practice

The following example illustrates how the course made good may be found using this principle.

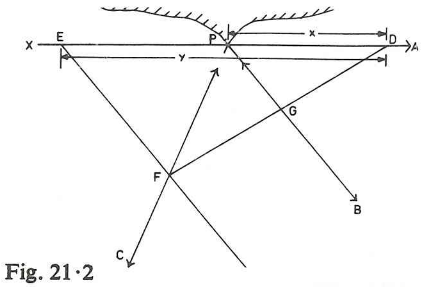


Fig. 21·2

Suppose that the Point P illustrated in fig. 21·2 is observed on three successive instants and that the three position lines PA, PB and PC, are obtained. If the distance travelled between the times of observing the first and second bearings is x ml., and the distance travelled between the times of taking the second and third bearings is y ml., the course made good between the times of the first and third bearings may be found as follows:

Referring to fig. 21·2, produce AP to X. Mark off any distance PD from P towards A to represent x ml. From D mark off on the same scale a distance DE to represent y ml. From E draw a line parallel to the middle position line PB to cut the third position line PC at F. Join D to F. The direction of DF is that of the course made good between the times of the first and third observations.

It must be appreciated that only the direction is found from this information. The line DF does NOT represent the track that the vessel has made good during the interval between the times of taking the first and third bearings. To find the actual track made good additional information is necessary.

The scale of units along the line AX, which is the ratio line, is chosen as convenient. The larger the scale the more accurate will be the result. This follows because the larger is the scale the longer will be the line DF, and the longer is a line the more accurately may its direction be measured.

Fig. 21·3 illustrates the triangles relating to the problem demonstrated above. By comparing triangles DPG and DEF it will be seen that they are similar. Therefore:

$$DP : DE :: DG : DF$$

But: $$DP : DE :: x : y$$

Thus: $$DG : DF :: x : y$$

If follows that because D and E lie on the first and third position lines, respectively, DF must lie in the direction of the course made good.

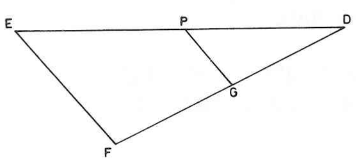


Fig. 21·3

If the vessel is fixed on any of the three position lines or, indeed, at any other position: by a vertical sextant angle; a sounding; a position line obtained from a bearing of a second mark; or, by any other means, the actual track made good over the ground may be found: this, simply, by drawing a line parallel to DF through the fix.

If the actual track of a vessel is known, the effect of any current that may have been acting may be found by comparing the course and distance made good, found from the chart, with the course and distance travelled through the water.

3. Examples

The following examples, which illustrate the three bearing problem, should be studied closely.

Example 21·1—Light vessel A was observed to bear 140° at 1000 hr.; 090° at 1015 hr.; and 040° at 1035 hr. Find the course made good.

Referring to fig. 21·4:

$$AX : AY :: 15 : 20$$

$$\text{Course direction} = XZ$$
$$= 185° \text{ (By measurement)}$$

Answer—Course = 185°.

Example 21·2—A vessel is heading 250° and logging 15·0 knots. Point A is observed to bear 310° at 0900 hr.; 355° at 0930 hr.; and 050° at 1030 hr. The distance off the point at 0900 hr. was 13·0 ml. Find the set and rate of the current.

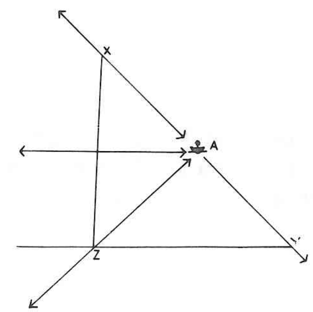


Fig. 21·4

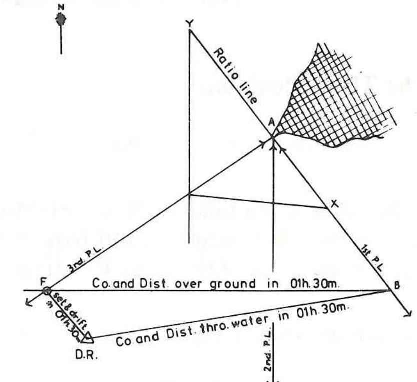


Fig. 21·5

Refering to fig. 21·5:

Set and Rate (by measurement) = 275° × 6·0 knots

Answer—Set = 275°
Rate = 6·0 knots.

Exercises on Chapter 21

1. Explain the principle of the Three Bearing Problem.
2. A lighthouse bore 010° at 1000 hr.; 340° at 1015 hr. and 310° at 1030 hr. Find the course made good.
3. A tower bore 270° at 1000 hr. when the log registered 15·0. When the log registered 20·0 the tower bore 230°, and when the log registered 23·0 the tower bore 185°. Find the course made good.
4. Heading 175°, the V.S.A. of a lighthouse abeam to port was 1° 05′ 00″. The charted height is 200 ft. 25 minutes later the lighthouse bore 065°, and after a further 15 min. it bore 037°. Find the distance off the lighthouse at the time of the third observation.
5. A lighthouse bore 160°. After 15 min. it bore 105° and a sounding fixed the vessel at a distance of 4·0 ml. from the lighthouse. After running for 12 min. the lighthouse bore 085°. Find the distance off the lighthouse at the time of the last observation. The vessel was heading 235° and logging 15·0 knots. Find the set and rate of the current.
6. Heading 322° (C) variation 5° W., deviation 4° E. A lighthouse bore 020° (C). After running 4·0 ml. through the water it bore 038 (C) and after running a further 3·0 miles it bore 063° (C), at which time it was found to be 5·0 ml. off. Find the course made good and the drift of the current the set being known to have been 090°.

CHAPTER 22

THE THREE POSITIONS: CURRENT SAILING

1. The Three Positions

(i) *Observed Position (Obs.) or Fix (⊙)*

A position obtained from observation of celestial bodies is known as an Observed position (Obs.). A position found from observations of Land-or sea-marks is known as a fix. In practice the terms Observed Position and Fix are often used synonymously.

(ii) *Dead Reckoning Position (D.R.) (×)*

A Dead Reckoning Position is one that is found from the compass and the log. The course and distance made through the water, as found from log and compass, when applied to the last observed position or fix, gives a D.R. position. No allowance is made for the effect of wind or current.

(iii) *Estimated Position (E.P.) (⟁)*

As its name implies, an Estimated Position is a position at which a vessel is estimated to be at any given time. It is the most likely, or most probable position of the vessel ascertained without celestial or terrestrial observations. It is based on course and distance since the last known position with estimation made for the effect of wind and current by extrapolation from earlier fixes.

It should be noted that a vessel is seldom at her D.R. position. This follows from the simple reason that there is almost always some factor or factors which influence the motion of a vessel besides the engines and the helmsman.

When observations are unobtainable or unreliable, and it is desired that a vessel's position be plotted on the chart, the D.R. position is first laid down by applying to the last observed position courses and distances made through the water. Allowances are then made for the estimated set and drift of the current; leeway; heave of the sea; bad steering; and alterations of course that may have been made to avoid other vessels, in order to derive an estimated position. A great deal of experience and skill is necessary to estimate accurately the effects of each of these factors responsible for throwing the vessel off her anticipated track. The best navigator may be said to be the one who can give the best estimated position at any time.

2. Other Navigational Terms

(i) Course—The intended heading.
(ii) Track—The path followed or to be followed between one position and another. This path when it is over the ground is called the Ground Track (→→) or when it is through the water is called the Water Track (→). The term water track is used to denote the track which the ship actually makes through the water.
(iii) Leeway—Is the effect of wind in moving a vessel bodily to leeward.
(iv) Leeway Angle—Is the angle between the water track and the ship's head.
(v) Set—The direction towards which a current and/or tidal stream flows.
(vi) Drift—The distance covered in a given time solely to the movement of a current and/or tidal stream.
(vii) Drift Angle—The angular difference between the ground track and water track.

3. Examples

Example 22·1—A vessel's observed position is found to be in Lat. *X*° N., Long. *Y*° W. The vessel runs on a course of 060° through the water and logs 60 ml. During this time the current was estimated to have set the vessel 160° for 10 ml. The wind, which blew from the N.W., was estimated to have caused a leeway of 5°. Plot the vessel's estimated position. At this time the vessel's position was found to be 070° by 70 ml. from the observed position found earlier. This position was found from shore bearings. Plot the vessel's position and estimate the accuracy of navigator's estimations of the effects of current and wind combined.

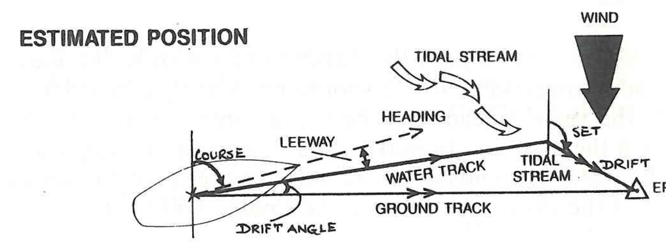


Fig. 22·1

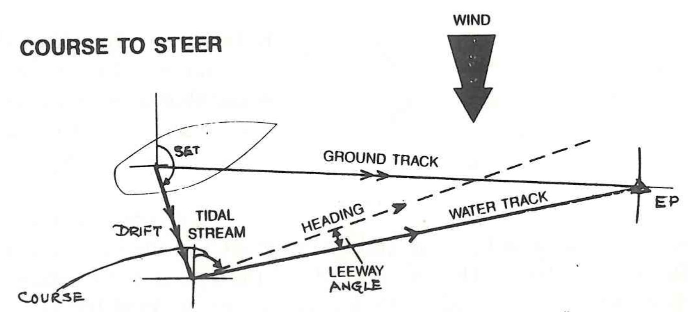


Fig.22·2

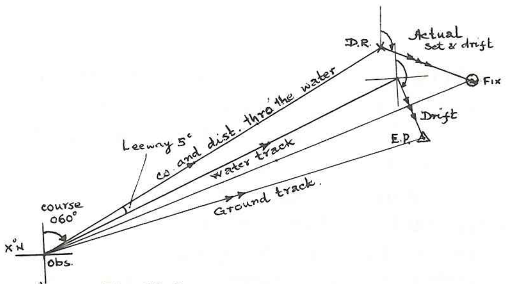


Fig. 22·3

Referring to fig. 22·3 the vessel's observed position, D.R. position, Estimated position, and Fix, are illustrated in the traditional way.

Had the vessel's reckoning, or record of course and distance through the water, been accurately made, the estimation of the combined effect of current and wind was in error to the extent of the distance between the E.P. and the Fix. By measurement, this is about 12 ml.

If, during the run, the wind had not affected the vessel's movement, the actual set and drift of the current may be taken as being equivalent to the course and distance from the D.R. position to the Fix. The D.R. position, it should be noted, has value in finding the actual set and drift of a current for any given interval.

4. Current Sailing

When a course line has been laid down on a chart the navigator should estimate the probable effect of current and make allowance for this in finding the required course to steer.

In order to understand the principle of finding the course to steer to counteract the effect of a given current it is necessary to have a knowledge of the principle of the parallelogram of Velocities.

Suppose that a vessel has to be steered along a path the direction of which is due East. Suppose that a current is known to be setting 045°. Now it should be clear that in order to counteract the effect of this current, the vessel's head must be set in some direction to the southwards of East. The angle between the direction to make good: that is to say, due East, and the direction to steer through the water, depends upon the relative speeds of the vessel and the current. The faster the vessel or the slower the current, the smaller will be the angle, and conversely.

The course to steer through the water may be found by a clumsy trial-and error method which is illustrated as follows.

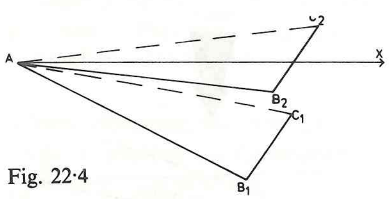


Fig. 22·4

Referring to fig. 22·4, the direction AX is the direction to make good over the ground. Suppose that the vessel is capable of making distance AB in a given time in still water; and suppose that the drift of the current, in the same interval, is equal to BC.

If the vessel's head is set in the direction AB_1, she would make good course and distance AC_1 in the time taken to make AB_1 through the water. Because C_1 lies to the southwards of the line AX, the angle which the vessel's head has been directed south of East is, therefore, too great. Had the vessel's head been set in the direction AB_2, she would have made good the course and distance AC_2. Because C_2 lies to the northwards of the line AX, it follows that the angle the vessel's head has made with the

direction to make good, is too small. AB must lie in such a direction that the effect of the current will keep the vessel on the line AX. This is illustrated in fig. 22·5.

Fig. 22·5

If the set and rate of the current and the vessel's speed remain constant, the vessel will always lie on the line AX, but the vessel's head will always lie in the direction AB.

The direction AB could have been found very simply, compared with the trial-and-error method used above, by the method illustrated in fig. 22·5.

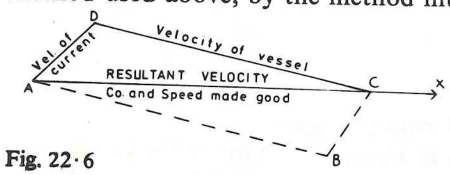


Fig. 22·6

Referring to fig. 22·6; by marking off, from position A, a distance AD to represent the velocity of the current; and, from the end of that line, marking off a distance DC to represent the speed of the vessel, such that this line terminates on the line AX, the direction of the course to steer, that is to say, AB, is immediately ascertained.

It should be remembered that the term Velocity means "Speed in a Given Direction". The lines representing the velocities may be drawn to any convenient scale of knots. Whatever scales is used, the direction AB will always be found to be the same.

The line AC represents the velocity made good. This is the resultant of the velocities, respectively, of the vessel through the water and the current.

When two velocities act simultaneously on a point, the resultant velocity of the point may be found by the principle known as the Parallelogram of Velocities. This is explained thus:

Draw from a common point two lines to represent, respectively, the component velocities. Let these two lines be the adjacent sides of a parallelogram, the diagonal of which, drawn from the same common point, represents the resultant velocity.

There are two, and only two, common problems pertaining to current sailing which are based on the principle of the parallelogram of velocities. These are:

(i) Given a vessel's course and speed through the water, (watertrack) and the set and rate of the current, to find the course and speed made good, (groundtrack)

(ii) Given the course to make good, the vessel's speed through the water, and the set and rate of the current, to find the course to steer through the water, (watertrack) and the speed made good over the ground.

The following examples should be studied closely.

Example 22·2—A vessel is heading 075° and logging 10·0 knots. The current set 150° at a rate of 5·0 knots. Find the groundtrack.

In fig. 22·7:

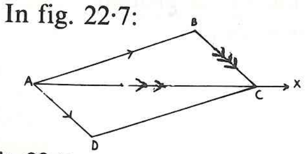


Fig. 22·7

AB = Velocity through Water = 075° × 10·0 knots
AD = Velocity of Current = 150° × 5·0 knots
AC = Velocity made good over ground
By scale drawing—AC = 098° × 12·0 knots

Answer—Course and Speed made good = 098° at 12·0 knots

N.B.—In practice it is not usual to draw the complete parallelogram as we have done in fig. 22·7. The triangle ABC is sufficient. At the end of the line AB, which represents the velocity of the vessel through the water, the line BC, to represent the velocity of the current, is drawn so as to terminate on the line drawn in the direction to make good.

Example 22·3—Find the course to steer to counteract the effect of a current which sets 150° at the rate of 5·0 knots, in order to make good a course of 098°. Find the speed made good if the speed of the vessel through the water is 10·0 knots.

In fig. 22·8:

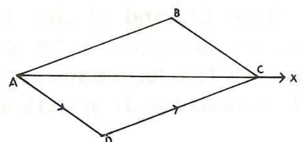


Fig. 22·8

AX = required ground track
AD = Velocity of Current = 150° × 5·0 knots
DC = Speed through water = 10·0 knots
AC = Course and Speed made good
By scale drawing: AC = 075° × 12 knots

Answer—Course and speed made good = 075° at 12 knots.

In the above example, which should be compared with Example 22·2, it is necessary only to draw the lower half of the parallelogram. From the end of the line AD, which represents the velocity of the current, the line DC is drawn to represent the speed of the vessel. This line terminates on the line which represents the direction to make good.

Exampled 22·4—A point bears 150° distanc 32·0 ml. Find the course to steer, and also the time taken to reach the point, in a current which sets 270° at a rate of 3·0 knots, and the speed of the vesel through the water is 10·0 knots.

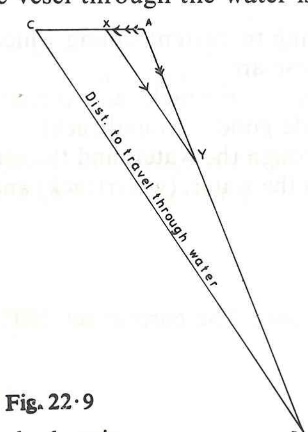


Fig. 22·9

In fig. 22·9:

A represents the position of the vessel
B represents the position of the point
AX = velocity of current
XY = speed of vessel in direction to steer
AY = speed of vessel over ground

$$\text{Time Taken} = \frac{\text{Distance made through the water}}{\text{Speed through the water}} = \frac{\text{Distance made over ground}}{\text{Speed over ground}}$$

By scale drawing:

$$\text{Time Taken} = \frac{BC}{10} = \frac{40}{10} = 4{\cdot}00 \text{ hr.}$$

Course to steer = 145°

Answer—Time taken = 4 hr. 00 min.
Course = 145°.

Exercises on Chapter 22

1. Distinguish between: Observed Position; D.R. Position; Estimated Position.
2. Explain clearly the principle of the Parallelogram of Velocities, and show how it is used in current sailing.
3. Set course to make good a direction of 170° when the current sets 040° at the rate of 3·0 knots, given that the speed of the vessel through the water is 10·0 knots.
4. Set course to make good 100° if the vessel's speed through the water is 12·0 knots, and the current is estimated to be 040° at 4·0 knots. If the vessel's speed is reduced to 6·0 knots, what adjustment will have to be made to the course steered?
5. A vessel was heading 170° at a speed of 12·0 knots. The current was estimated to be setting 100° at a rate of 3·0 knots. Find the course and speed made good.
6. A point of land bore 295° (C). Variation = 13° W., Deviation = nil on all headings. Set compass course for the point in order to counteract the effect of a current setting 000° at a rate of 5·0 knots, given that the vessel's speed is 12·0 knots.
7. A point of land lies 265° at a distance of 63 ml. A current is estimated to be setting 030° at a rate of 2·5 knots. Find the course to steer to reach the point if the vessel's speed is 12·0 knots. After travelling for 4·00 hr. the point was observed to bear 320° at a distance of 5·0 ml. Find the actual current that has affected the vessel during the interval.
8. A light vessel bears 176° at a distance of 15·0 ml. Find the course to steer to reach the light vessel if the vessel's speed through the water is 10·0 knots. The current is estimated to be setting 285° at a rate of 3·0 knots. Find the time taken to reach the light vessel, and the distance travelled through the water in the interval.
9. The current is estimated to be setting 060° at a rate of 4·0m knots. The vessel's speed is 13·0 knots. The wind is North and leeway is estimated to be 10°. Find the course to steer to make good 282°.
10. Explain why a vessel is seldom at her D.R. position.

CHAPTER 23

POSITION LINE BY RADIO BEARING

1. Introduction

Most large vessels are required by law to be fitted with Medium Frequency Radio Direction Finding equipment, by means of which radio bearings of Radio Beacons and other radio transmitters may be observed. A Radio Beacon transmits a radio signal on a specified frequency. When transmitting, radio energy is broadcast, or thrown out in all directions, from the beacon, and the ray of energy received at a vessel is that which has travelled along the shortest route between the beacon and the vessel. This route is the great circle arc connecting the transmitter and receiver.

The course angle of a ray of radio energy varies along its path, unless the path coincides with a meridian or with the equator. The Direction Finder on board, when used to observe the bearing of a radio beacon, indicates the direction of the ray of energy as it arrives at the vessel. In order to obtain a position line from such an observation, the great circle bearing must be corrected to give the corresponding rhumb-line or Mercatorial Bearing, which may be laid down on the chart as a straight line (see para. 3).

Many shore-based radio stations are equipped with radio finding equipment by means of which the radio bearing of a vessel may be obtained. These stations provide a service whereby the position of a vessel even if not fitted with a direction finder may be found from radio cross bearings observed ashore. The navigator wishing to avail himself of this service contacts the station by radio. On receipt of instructions from the station the vessel transmits her radio call-sign. This signal is received at the station and a bearing of the vessel obtained. The observed bearing is then transmitted to the vessel and a radio position line obtained therefrom.

2. Convergency of the Meridians

It will be remembered that all meridians converge towards the Earth's poles. Moreover, all great circles, except the equator and meridians, cross meridians at ever-changing angles.

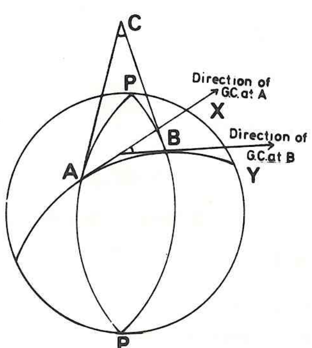


Fig. 23·1

The convergency of the meridians of two places A and B, is equal to the angle between the tangents lying in the planes of the meridians at the two places. This angle is also equal to that of the change in the direction of the great circle passing through A and B.

In fig. 23·1 the convergency of the meridians at A and B is equal to the angle ACB. This is equal to the angle between AX and BY, the tangents, respectively, to the great circle arc AB at A and B.

The magnitude of convergency depends upon:

(i) The difference of Longitude between the two places.
(ii) The Middle Latitude of the two places.

If both places lie on the equator, convergency is zero, because the equator does not change its direction, this being due East or due West.

If both places lie on the same meridian, convergency is zero for meridians do not change direction, this being due North or due South.

As Latitude increases convergency between two meridians also increases from zero at the equator to a maximum at the poles where convergency equals D. Long.

$$\text{Convergency} \propto \text{sine Latitude}$$
$$\text{Convergency} \propto \text{D. Long.}$$

$$\text{Convergency (in °s)} = \text{D. Long. (in °s) . sin Middle Latitude}$$
$$\text{Convergency (in 's)} = \text{D. Long. (in 's) . sin Middle Latitude}$$

Referring to fig. 23·2:

$$\text{In Lat. } 0° : \text{convergency} = 0°$$
$$\text{In Lat. } X° : \text{convergency} = x°$$
$$\text{In Lat. } 90° : \text{convergency} = D° = \text{D. Long.}$$

The convergency may conveniently be found from the Traverse Table, as indicated in fig. 23·3.

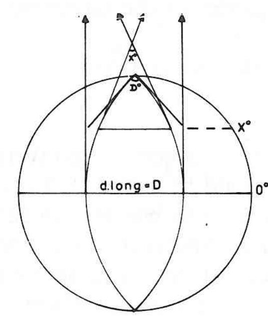


Fig. 23·2

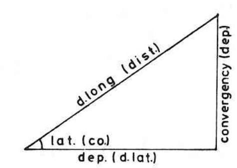


Fig. 23·3

Referring to fig. 23·3:

$$\text{convergency} = \text{D. Long. sin Lat.}$$

Enter Traverse Table with Latitude as a Course and D. Long. in the Distance column. Convergency is then lifted from the Departure column.

3. The Half-Convergency Correction

Fig. 23·4 represents a portion of the Earth's northern hemisphere on a Mercator Chart. Let B and A represent a vessel and a radio beacon, respectively. The curved line represents the great circle arc joining A and B.

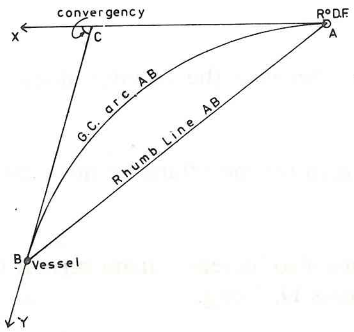


Fig. 23·4

Imagine that a ray of radio energy, transmitted by the beacon A, is received at vessel B. The path of this ray is the curved line AB: its initial direction is along AX and its final direction is along BY—these directions being tangential to the great circle arc AB at A and B, respectively. The change in the direction of the ray between the beacon and the vessel is, therefore, equal to the angle XCY, and this is the convergency.

The radio bearing of beacon A indicated by the direction finder on board vessel B, is the direction BC. In order to obtain a position line, the direction BA must be found: this being the rhumb-line, or Mercatorial Bearing.

In triangle ABC the sum of the angles CBA and CAB equals the angle BCX: the exterior angle of the triangle ABC. It is assumed that angle CAB is equal to angle CBA. This is a reasonable assumption because angle XCB is usually very small. Thus, angles CAB and CBA are each equal to half the convergency XCB. To find the rhumb-line bearing of A from B half-convergency is, therefore, applied to the great circle, or observed radio, bearing.

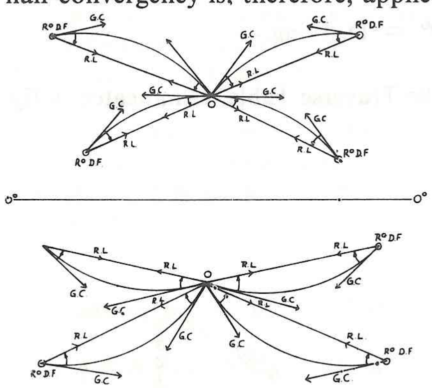


Fig. 23·5

Fig. 23·5 serves to illustrate that the Half-Convergency Correction is to be applied equatorwards to the great circle bearing to obtain the corresponding Mercatorial bearing. This is always the case and applies to the circumstance in which the station takes the bearing of the vessel as well as that in which the vessel takes the bearing of the station.

Whilst on the subject of convergency of the meridians, it should be noted that a visual bearing is, in fact, a great circle bearing. In gerneral, the D. Long. between an observer and an observed land- or sea-mark is small, in which case the half-convergency correction is negligible and may, therefore, be ignored. In ignoring the half-convergency correction the rhumb-line and the great circle bearing are considered to be coincident, and the bearing is laid down on the chart as a straight line. In high Latitudes, however, the D. Long. between an observer and an observed mark may be considerable even though the distance between them may be relatively small. In this circumstance it may be necessary to apply the appropriate half-convergency correction to the observed bearing in order to obtain a rhumb-line bearing before plotting on the chart.

The accuracy of a radio bearing depends, in part, on the quality and calibration of the Direction Finder. It also depends upon the structure of the vessel and the location of the D.F.

aerial. It is also influenced by the nature of the surface over which the radio energy has travelled in passing from the transmitter to the receiver. These matters are discussed in Chapter 45.

Position lines obtained from radio bearings are not reliable when the distance between the transmitter and the receiver is more than a hundred miles or so. This is so because the accuracy of radio bearings is relatively coarse—usually not better than about one degree. It is interesting to recall than an error of 1° in laying down a position line results in an error of one mile for every 60 miles of distance between the observer and the observed mark. This is illustrated in fig. 23·6.

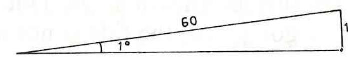


Fig. 23·6

The reader is advised to examine carefully the contents of the two parts of Volume 2 of the *Admiralty List of Radio Signals*, which deal with all aspects of Medium Frequency Radio Direction Finding.

Exercises on Chapter 23

1. Explain carefully how a position line is obtained from a radio bearing.
2. Show that the convergency of the meridians of two places is equal to the D. Long between the places multiplied by the sine of their Middle Latitude.
3. What is the connection between convergency and departure? Explain how convergency may be found by means of the Traverse Table.
4. Why is the Half-Convergency Correction always applied equatorwards to a great circle bearing in order to find the corresponding rhumb-line bearing?
5. Explain why the correction to apply to a great circle bearing to obtain a corresponding rhumb-line bearing is equal to half the convergency between the meridians of the station and the vessel.
6. A vessel in approximate position Lat. 50° 00′ N. Long. 20° 00′ W., obtains a radio bearing of Land's End Radio Station in Lat. 50° 00′ N. Long. 05° 00′ W. Find the Mercatorial bearing if the radio bearing is 085°.
7. Explain why position lines obtained from radio bearings are not reliable when the distance between the vessel and the beacon is more than a hundred miles or so.
8. What factors influence the accuracy of radio bearings?
9. Explain how the *Admiralty List of Radio Signals*, Vol. 2, is used.
10. Explain why it may be necessary to apply a half-convergency correction to a visual bearing taken in high Latitudes.

CHAPTER 24

TIDES

1. The Tide

Observation of the level of the sea surface against a graduated post, or Tide Pole erected vertically on the sea-bed, reveals the vertical oscillation of the sea surface known as the Tide. Notice that, although we talk loosely about the tide coming in or going out, the tide is not a horizontal movement: it is a vertical motion of sea level.

The height of sea level above a given fixed reference level, plotted as a graph against time, produces a Tidal Curve. A typical tidal curve is illustrated in fig. 24·1.

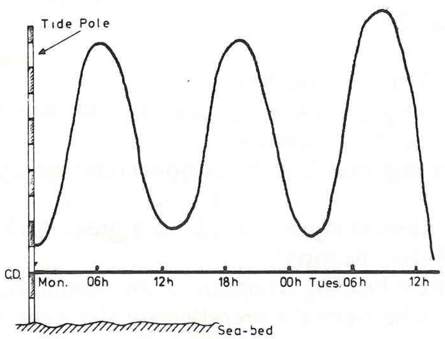


Fig. 24·1

It will be noticed that the curve illustrated in fig. 24·1 approximates to a sine (or cosine) curve. It follows that the rate of rising or falling of sea level is not uniform. The rate is greatest at the mid-time of the instants when the sea level ceases to fall (or rise) and the following occasion when it ceases to rise (or fall). When, at any place, the sea level ceases to rise and before it commences to fall, it is said to be High Water at the place. When the sea level ceases to fall and before it commences to rise it is said to be Low Water at the place.

The interval between the times of any given High Water (H.W.), or low water (L.W.) and the succeeding Low Water or High Water, is known as the Duration of the Tide. The interval between the times of successive H.W.s (or L.W.s) is known as the Period of the Tide. The vertical distance between the levels of H.W. (or L.W.) and the following L.W. (or H.W.) is known as the Range of the Tide.

Examination of a tidal curve reveals that the period and range of the tide at the place for which the curve applies are by no means constant. Moreover, the tidal curves of different places vary in period and range.

The level of the sea surface in coastal waters is usually referred to a level known as Chart Datum. This is a level adopted by the hydrographic surveyor and is the level above which charted depths or soundings are given, and this is the reason why it is called Chart Datum (C.D.).

At most places, especially European and North American harbours, the sea level rises and falls twice each day, so that the duration of the tide is about 6 hours and the period of the tide about 12 hours. At such places the tide is said to be Semi-Diurnal, because the period of the tide is about half a day. At other places, notably in the Pacific, the tide is Diurnal, which means that the period of the tide is about 24 hours, so that each day experiences only one H.W. and one L.W.

Investigation into the causes of the tide has engaged the attention of numerous philosophers down the ages. So complex are the factors which influence the tide that, even at the present time, the state of understanding of all tidal phenomena has not reached perfection.

Before dealing with the practical problems of the tide as they affect the navigator we shall discuss briefly certain aspects of tidal theory.

2. The Equilibrium Theory of the Tide

The basis of tidal prediction of the times and heights of H.W. and L.W. at given coastal locations is the Equilibrium Theory. According to this theory every particle of water on the Earth is in a state of balance, or equilibrium, under the action of several component tidal forces which act on it.

The tide, according to the Equilibrium Theory, is due to the forces which act between the Earth, Moon, Sun, and water on the Earth; and to the motions of the Moon and Sun relative to the Earth. The Earth's motion on its axis is also to be considered.

The Equilibrium Theory is due, primarily, to the great English philosopher Sir Isaac Newton, in whose Universal Law of Gravitation it is stated that a force is exerted between every two bodies in the universe, the magnitude of the force being dependent upon the masses of, and distance between, the bodies. The force varies directly as the product of the masses of the bodies and inversely as the square of their distance apart. The law is expressed thus:

$$F \propto \frac{m_1 \cdot m_2}{d^2}$$

where F is the force, m_1 and m_2 the masses of the bodies, and d their distance apart.

3. Effect of Earth's Rotation on Tides

Because the Earth rotates every particle of water on its surface, except particles at the Earth's poles, experiences a centrifugal force which acts perpendicularly to the Earth's axis of rotation. This force varies as the cosine of the Latitude, being maximum at the equator and zero at either pole.

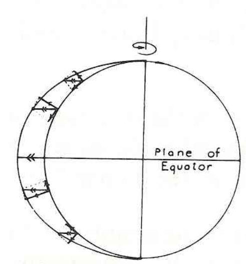


Fig. 24·2

Centrifugal force may be resolved into vertical and horizontal components. The vertical component, which acts vertically upwards, acts against the downward-acting force of gravity. The horizontal component acts towards the equator, so that every particle of water on the Earth tends to move meridianally towards the equator; thus, there is a tendency to cause a piling of water at the equator.

Centrifugal force alone considered, the water level would be at a maximum height above the solid Earth's surface at the equator, and this height would decrease polewards. This is illustrated in fig. 24·2.

In examining the causes of the tide it is usual to regard the Earth as being a smooth sphere completely covered with water. When this ideal condition has been considered allowances are made for the effects of continents; shallow water; configuration of the coasts; and friction between the water and the solid Earth's surface.

Let us first consider the effects of the Moon's and Sun's gravitational forces on the Earth and its waters.

4. The Moon's Effect

Although we say, in a loose way, that the Moon revolves around the Earth, the fact is that the Earth and Moon revolve, once a month, about each other.

The point about which the Earth-Moon system revolves is the common centre of gravity of the system. This is a point known as the Barycentre. The barycentre is located on a line joining the centres of gravity of the Earth and the Moon at a point about 1000 miles below the Earth's surface.

In fig. 24·3, *B* represents the barycentre.

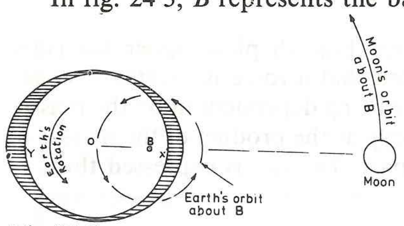


Fig. 24·3

Discounting all forces other than internal forces of the Earth-Moon system, every particle of matter within this system is acted upon by a Gravitational Force of Attaction and a Centrifugal Force due to the revolution of the system about the barycentre. In these circumstances the motions around the barycentry are in equilibrium. It follows that the resultant gravitational attraction of the Earth and Moon, which tends to draw these bodies together, is exactly neutralized by the resultant centrifugal force which tends to force them apart.

Gravitational and centrifugal forces acting on particles at the Earth's and Moon's centres are exactly balanced, but all other particles are acted upon by a resultant gravitational/centrifugal force, which acts towards or away from the Moon.

On the hemisphere of the Earth under the Moon centrifugal force is less than gravitational force; and the water, therefore, being mobile, responds by piling up under the Moon at point *X* in fig. 24·3. On the other hemisphere centrifugal force exceeds gravitational force and the water tends to pile up at point *Y* denoted in fig. 24·3. At every point on the great circle whose poles lie at *X* and *Y*, there tends to be Low Water. In other words, the resultant force acting upon the water—a force called the Moon's Tide-Raising Force—tends to produce an ellipsoidal water surface as illustrated in fig. 24·3.

We must imagine the major axis of the ellipsoid of water to be locked in the direction of the Moon from the Earth's centre. The rotation of the Earth within this ellipsoid of water results in the periodic rising and falling of sea level, which is referred to as the Lunar Tide.

The period of the lunar tide is half a lunar day. The lunar day has a variable length but its average value is 24 hr. 50 min., so that the period of the lunar tide is 12 hr. 25 min. on average.

5. The Sun's Effect

What has been said in respect of the Moon applies, in principle, to the Sun. The Earth and Sun revolve around their common centre of gravity, and the effect of gravitational and centrifugal forces give rise to the Solar Tide. The solar tide has a period of 12 hrs., and it is said to be due to the Sun's Tide-Raising Force.

The solar tide-raising force is smaller than that of the Lunar: the ratio between them being about 34 : 15, or less accurately 7 : 3.

6. The Luni-Solar Tide

The combination of the lunar and solar tides is known as the Luni-Solar Tide. At New Moon and Full Moon the tide-raising forces of both Moon and Sun act conjointly. The tides resulting on these occasions are known as Spring Tides. The term "spring" comes from the Saxon word "Springan" which means "to swell", and the term Spring Tides applies to the greatest range during the tidal cycle of a fortnight.

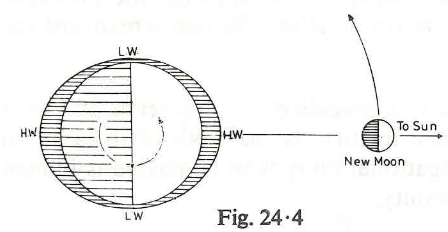


Fig. 24·4

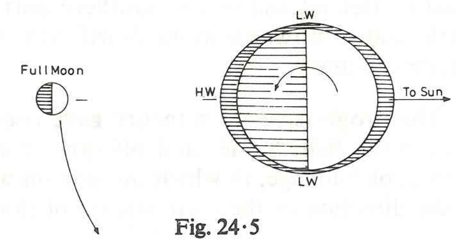


Fig. 24·5

Fig. 24·4 illustrates the Spring Tide which occurs at the time of New Moon, when the Age of the Moon is 00 days. Fig. 24·5 illustrates the Spring Tide which occurs when the Moon is Full and its age is 14½ days.

When the Moon and Sun are in quadrature; that is to say, when the Moon is at the First or Last Quarter, and the Age of the Moon is 07 or 21 days, respectively, the luni-solar tide is called a Neap Tide. The word "neap" is derived from the Saxon word "neafte" which means "a scarcity", and the tides that occur at the First and Third Quarters of the Moon are called Neap Tides because they are the tides of least range during the tidal cycle of a fortnight.

Fig. 24·6 illustrates conditions giving rise to neap tides.

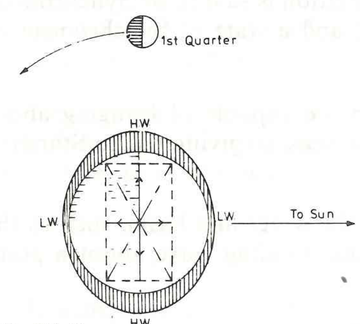


Fig. 24·6

At Springs the range of the tide is maximum. From the time of Springs to that of the following Neap Tide, the range of the tide diminishes, and successive H.W.s have decreased heights, and successive L.W.s have increased heights.

At Neaps the range of the tide is minimum. From the time of Neaps to that of the following Springs the range of the tide increases, and successive H.W.s have increased heights,and successive L.W.s have decreased heights.

Fig. 24·7 illustrates the various tidal levels and the more common tidal terms.

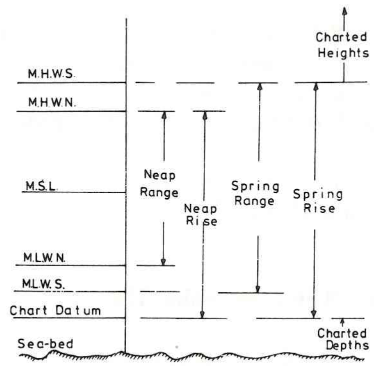


Fig. 24·7

7. The Progressive Wave Theory of the Tide

According to the Progressive Wave Theory and ellipsoidal tidal wave is believed to exist only in the Southern Ocean surrounding Antarctica. The effect of the Earth's rotation is, according to this theory, responsible for the generation of branch waves, which emanate from the Southern ocean primary tidal wave, and which progress northwards into the three oceanic gulfs of the Atlantic, Indian, and Pacific Oceans.

It is according to this theory that the progressive tide wave in the Atlantic Ocean approaches North-west Europe and proceeds eastwards in the English and Bristol Channels; northwards off the West coast of Ireland and in the Southern part of the Irish Sea; eastwards through the Pentland Firth; and southwards in the North Sea, where it meets the English Channel stream off the Thames Estuary.

The progressive wave theory gave rise to the idea of a so-called Main Stream of Flood around the British Isles and off other coastlands. This, in turn, is the basis of the Lateral System of buoyage, in which the side on which a navigational buoy is to be passed is related to the direction of the main stream of flood in the vicinity.

8. The Standing Wave Theory of the Tide

In the Equilibrium and Progressive Wave theories of the tide, tidal phenomena are considered to be global in character. In modern ideas on tidal theory, the tide is considered to be more of a local phenomenon. The rising and falling of sea level in a peripheral sea, or a bay or gulf, is likened to the oscillation of the free surface of a fluid in a container, when a periodic force acts on the container.

For a given container of liquid having a free surface there is a particular frequency at which a periodic force having this frequency will keep the liquid in the container in a constant state of oscillation. A periodic force resulting in such an oscillation is said to be Synchronous with the Natural Frequency of the liquid in the container, and a state of Synchronism or Resonance is said to exist.

The Moon and Sun provide the periodic forces which are capable of bringing about resonance in water bodies within the ocean and its peripheral seas, so giving rise to Standing Waves of Oscillation.

The effect of the Earth's rotation on the oscillations, of the water in a basin, such as the North Sea, for example, is to give a gyratory motion to the standing wave about a point called an Amphidromic Point.

At an amphidromic point the range of the tide is zero. Lines joining places at which the range of the tide is the same are called Co-Range Lines. These are roughly circular lines

centred at an amphidromic point. Lines which link places at which the times of High Water are the same radiate from amphidromic points. These are called Co-Tidal Lines.

An amphidromic point and its family of co-range and co-tidal lines forms an Amphidromic System. There are three such systems in the North Sea.

9. Priming and Lagging of the Tide

If the Moon alone caused the tide, the tidal day would correspond to the lunar day, which is 24 hr. 50 min., on average, of Mean Solar Time. If this were so the times of successive a.m. and p.m. High Waters would be later each day to the extent of about 50 minutes.

When the crest of the Solar Tide occurs before that of the Lunar Tide, the actual H.W. occurs before the time of the Moon's transit. As the Moon ages in the First and Third Quarters, the retardation of the tide is increasingly reduced. This means that the interval between the times of H.W. and the Moon's transit following the H.W. increases. When this happens the tide is said to Prime. The tide primes in the First and Third Quarters.

Fig. 24·8 illustrates the prime of the tide during the First Quarter.

During the Second and Fourth Quarters H.W. occurs after the time of the Moon's transit. When this happens, the effect on the interval between the time of the Moon's transit and that of the following H.W. is the reverse from what it is in the case of priming. In these circumstances the tide is said to Lag. Lagging is illustrated in fig. 24·9.

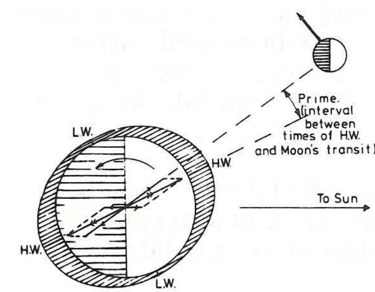


Fig. 24·8

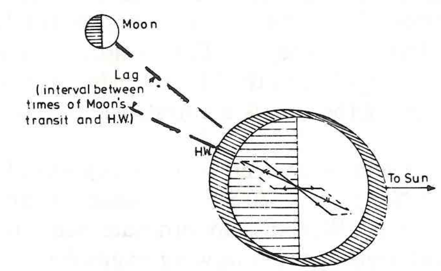


Fig. 24·9

10. Tidal Streams

The tide causes the sea level to vary between places. This difference of levels between places gives rise to horizontal motions of water known as Tidal Streams.

Tidal streams are pronounced only in relatively shallow waters. In the open oceans conditions are not conducive to the strong development of horizontal motions of water due to the tide. In coastal waters, however, tidal streams may reach speeds of many knots.

Tidal stream information is sometimes given on charts. It is also obtainable from Tidal Stream Atlases and, of course, from Tidal Tables.

It is interesting to note that tidal stream information is usualy related to the time of H.W. at a given port. For the British Isles the time of H.W. at Dover is commonly used for this purpose.

11. Practical Tide Problems

The *Admiralty Tide Tables* (A.T.T.) published by the Hydrographer of the Navy, is an annual publication in three volumes. Tidal data in Volume 1 are given for European waters; in Volume 2 for the Atlantic and Indian Oceans; and in Volume 3 for the Pacific Ocean.

Each volume of the A.T.T. consists of two main parts. In Volume 1, with which alone we shall be concerned, Part 1 contains daily predictions of the times and heights of H.W.s and L.W.s for a number of places called Standard Ports. A list of standard ports appears on the inside front cover of the A.T.T. Together with the daily predictions a Tidal Diagram is provided for each standard port. By means of the appropriate diagram, the time at which the tide has a given height, or the height of the tide for any given time, for any standard port, may be found.

Part 2 of the A.T.T. contains tidal data by means of which predictions of the times and heights of H.W.s and L.W.s for a large number of places called Secondary Ports may be found. These data are in the form of Time and Height Differences which are to be applied to the tabulated time and height of High or Low Water at a particular standard port in order to find the corresponding time and height at a given secondary port.

In addition to the principal tide tables contained in parts 1 and 2 there are several auxiliary tables to which the reader's attention is directed.

We have seen that the graph of the height of sea level against time is an approximate sine curve. At some standard and secondary ports the tidal curve for a given tide is almost a perfect sine curve, but at others the tidal curve is greatly distorted. In the tidal diagrams given in Part 1 of the A.T.T. two tidal curves are provided for each standard port. One of these curves applies to the Mean Spring Tide and the other to the Mean Neap Tide. At Springs the range of the tide is greatest, whereas at Neaps it is least.

It will be noticed on examination of the tidal diagrams for ULLAPOOL that the Spring and Neap curves are accompanied by an abscissa scale of time before or after the time of high water (H.W.) and an ordinate scale of factors. The method to use this tidal diagram is explained in the following examples.

Example 24·1—Find the height of tide at ULLAPOOL at 0431 hours on January 1st, 1987.

Ullapool tidal information on 1st January gives;
Predicted height of high water 5·3 m. at 0731 hours
Predicted height of low water 0·8 m. at 0731 hours

Range of tide 4·5 m. (a full spring range)

Steps to solving the problem:—(Refer to figure 24·10)

Using left hand half of the graph of Ullapool

(a) Mark the predicted height of high water along the top line (5·3m.)
(b) Mark the predicted height of low water along the bottom line (0·8m.)
(c) Join the marks with a straight line

Using the right hand half of the graph

(d) Write in the predicted time of high water in HW box on the bottom line (0731 hours)
(e) Write in the time values at one hour intervals as required along the bottom line
(f) Go to the required time along the bottom line (0431 hours or 3 hours 00 minutes before high water)
(g) Draw a line vertically upwards from this time (0431 hrs. or 3 hrs. BHW) and note where it cuts the spring curve
(h) Draw a line horizontally from this point towards the left to where it cuts the sloping line which you have just drawn (joining LW and HW)
(i) Draw a line vertically upwards and not where it cuts the top or bottom line (3·20m.)

Answer—The height of tide on 1st January at 0431 hours at Ullapool is 3·20 metres.

Ullapool Mean Spring and Neap Curve, extracted from A.T.T. Vol 1.

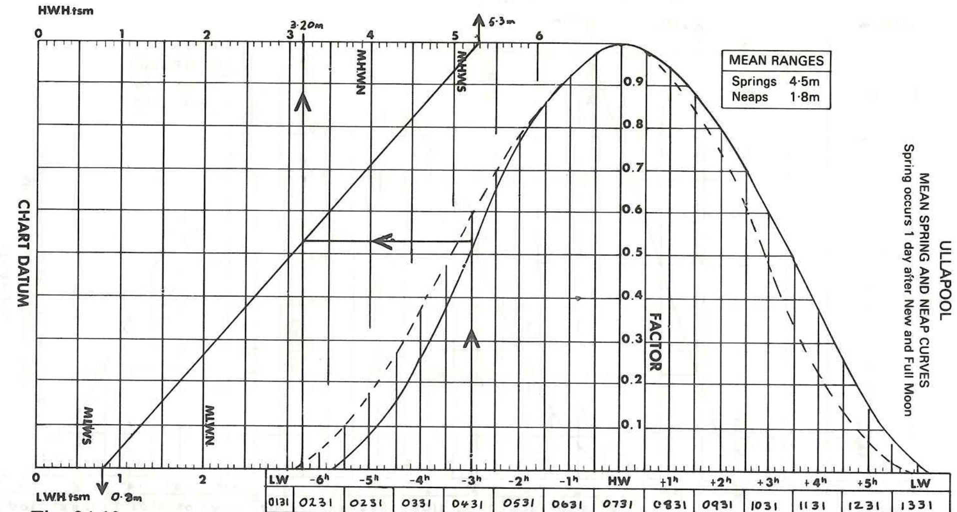


Fig. 24·10

Example 24·2—Find the height of tide at Ullapool at 0308 hours on Saturday 7th March, 1987.

From Tide Tables
Predicted height of high water 3·9 m. at 2308 hours on 6th
Predicted height of low water 2·1 m. at 2308 hours on 6th

Range of tide 1·8 m. (a Neap tide)

Steps to solving the problem (Refer to fig. 24·11)

The working out for this example is exactly the same as in example 24·1 except we now use the Neap curve.

Using the left hand half of the graph.
(a) Mark in the predicted height of high water along the top line (3·9 m.).
(b) Mark in the predicted height of low water along the bottom line (2·1 m.).
(c) Join the marks with a straight line.

Using the right hand half of the graph

(d) write in the predicted time of High water in HW box on the bottom line 2308 hours, 6th March.
(e) Write in the time values at one hour interval as required along the bottom line.
(f) Go to the required time along the bottom line (0308 hours or 4 hours 00 minutes after high water)
(g) Draw a line vertically from this time (0308 hours) and note where it cuts the neap curve.
(h) Draw a line horizontally from this point towards the left to where it cuts the sloping line which you have just drawn (joining LW and HW)
(i) Draw a vertical line and note where it cuts the top or bottom line (2·60 m.)

Answer—The height of tide on 7th March, at 0308 hours at Ullapool is 2·60 m. above chart datum.

Ullapool Mean Spring and Neap curve, extracted from A.T.T. Vol. 1.

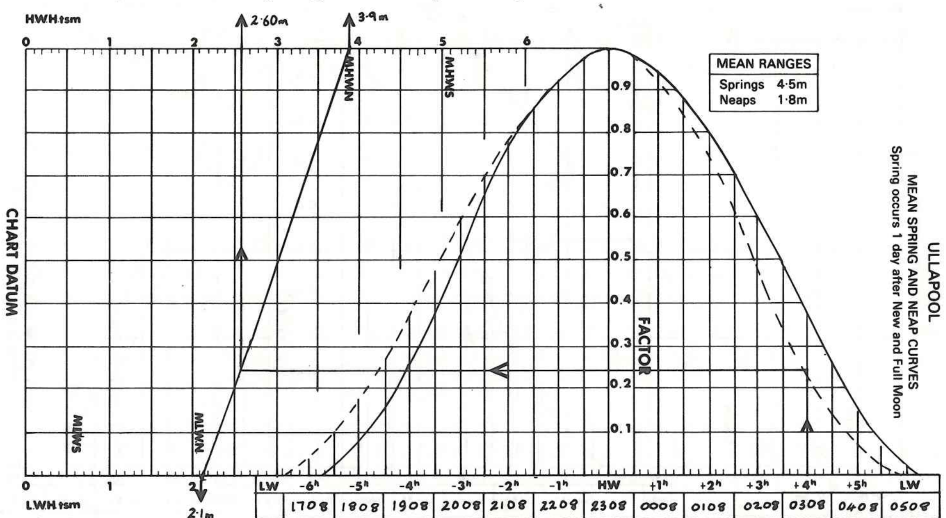


Fig. 24·11

Example 24·3—Find the height of tide at Ullapool on 5th January, 1987 at 1355 hours.

From Tide Table
Predicted height of high water 4·9 m. at 1055 hours
Predicted height of low water 1·1 m. at 1055 hours

Range of tide 3·8 m. (Range between Spring and Neap Tide)

The required time is (1355 − 1055) = 3 hours after high water.

Steps to solving the problem (Refer to figure 24·12)

Note: For those tides falling between Spring and Neap range, where a significant difference in curve is seen, one should plot from both the curves and interpolate

For tides falling outside the Spring and Neap range, extrapolation is not required.

Now, draw in straight line on left hand side of the graph, as explained previously using the figure 24·12 H.W. 4·9 and L.W. 1·1.

Write in the predicted time of H.W. (1055) and hourly intervals along the bottom line.

Required time along the bottom line is 1355 hours or 3 hours after high water.

Draw vertical line to cut SPRING curve and find the height above chart datum (3·4 m.)

Also, draw a vertical line to cut NEAP curve and find the height above chart datum (3·0 m)

Interpolate the height for the daily range as follows:—

Spring range	4·5 m.	Spring height	3·4 m. (from fig. 24·12)
Neap range	1·8 m.	Neap height	3·0 m. (from fig. 24·12)
Range difference	2·7 m.	Height difference	0·4 m.

Spring range	4·5 m.
Day range	3·8 m.
Range Difference	0·7 m. from spring range

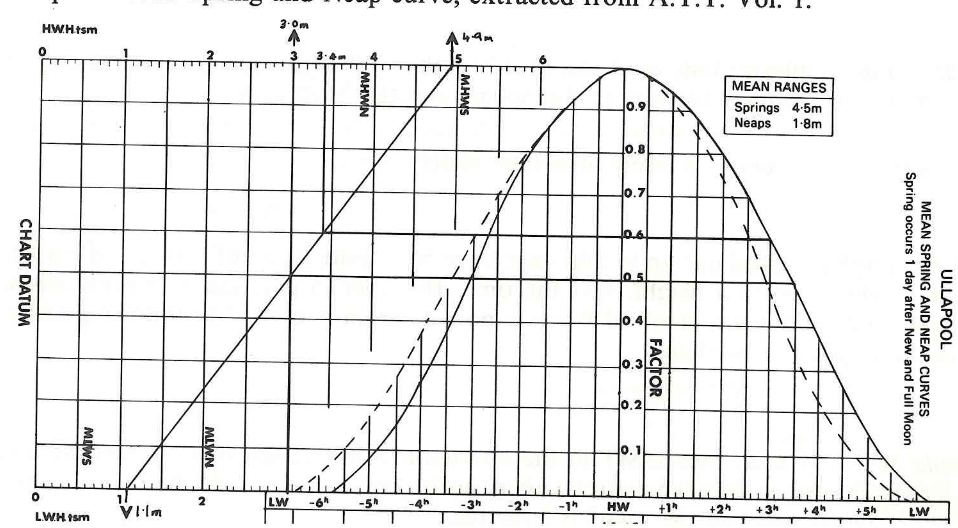
For a range difference of 2·7 m. we get a height difference of 0·5 m.

∴ for a range difference of 0·7m. we get $\frac{0{\cdot}5}{2{\cdot}7} \times 0{\cdot}7$
$= 0{\cdot}1$ m.

Spring height = 3·4
− 0·1 m.
Height of tide = 3·3 m. above chart datum.

Answer Height of tide at 1355 hours on 5th January is 3·3 m. above chart datum.

Ullapool Mean Spring and Neap curve, extracted from A.T.T. Vol. 1.



Note: For intermediate ranges, the interpolation is necessary. However, if and when the Spring and Neap curve co-inside then interpolation is not possible (see figure 24·12 from approximately 2 hours B.H.W. to ½ hour A.H.W.).

Example 24·4—At what time on January 1st, 1987 will the height of tide at Ullapool be 3·20 metres above chart datum?

Steps to solving the problem.

Using left hand half of the graph as in example 24·1

(a) Mark the predicted height of high water along the top line (5·3 m.).
(b) Mark the predicted height of low water along the bottom line (0·8 m.).
(c) Join the marks with a straight line.
(d) Write in the predicted time of high water with the H.W. box on the bottom line (0731 hours)
(e) Write in the time values at one hour intervals as required along the bottom line.
(f) find the height required (3·20 m.) on the top or bottom line using left hand half of graph.
(g) Read vertically to the sloping line.
(h) Read horizontally to the Spring curve.
(i) Read vertically downwards to give the time along the bottom line using the right hand half of the graph.

Answer—0431 hours or 3 hours before high water

Note: If the range is full neap as in example 24·2, the method is exactly the same except for (h) which is now read horizontally to neap curve. Answer 0308 hours or 4 hours after high water.

If the range is intermediate as in example 24·3 the method is exactly the same except for (h) which is now read horizontally to the Spring and the Neap curve.

Answer—1355 hours or 3 hours after high water.

The examples worked out up to this stage have been quite straightforward—given a time, find the height or given a height, find the time. However in practical tide problems some additional calculations are involved where a pole diagram is used. The following examples explain the method of working.

Example 24·5—At what time GMT in the afternoon will a vessel off Liverpool be able to cross a rock charted as dries 0·5 metres with an under keel clearance of 1 metre on December, 16th. 1987. The draught of the vessel is 5 metres.

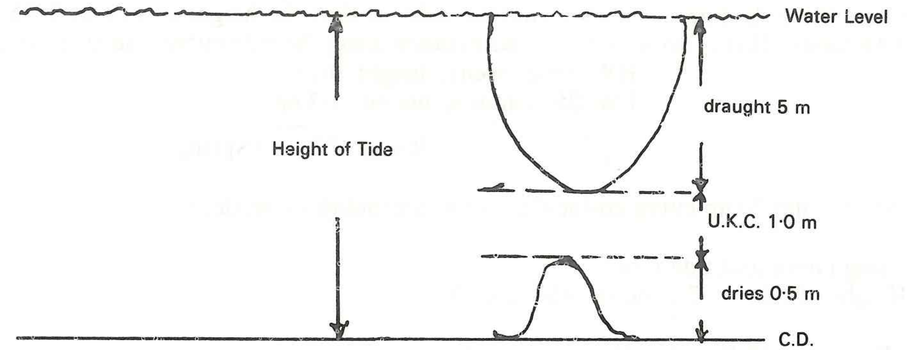


Fig. 24·13

From the pole diagram—
Height of tide required = drying height + U.K.C. + draught of vessel
= 0·5 m. + 1·0 m. + 5·0 m.
= 6·5 m.

Now, using tide table and tide curve for Liverpool find at what time in the afternoon of 16th December, 1987 the height of tide will reach 6·5 m.

Since it is in the afternoon, we need PM high water.

16th December H.W. 1927 hours, height = 7·8 m.
L.W. 1341 hours, height = 3·1 m.

Range = 4·7 m. (Neap tide)
(Since the Spring and Neap curve for Liverpool co-inside, we do not need to interpolate)
Height required = 6·5 m.
Using tide curve we get a time of 2 hours 10 minutes B.H.W.
H.W. time = 1927 hours
less = 0210

Time required = 1717 hours
Answer 1717 hours on 16th December.

Example 24·6—Find the height of a light at Liverpool charted as 25 metres at 0845 hours GMT on October 22nd, 1987. (given MHWS as 10 metres)

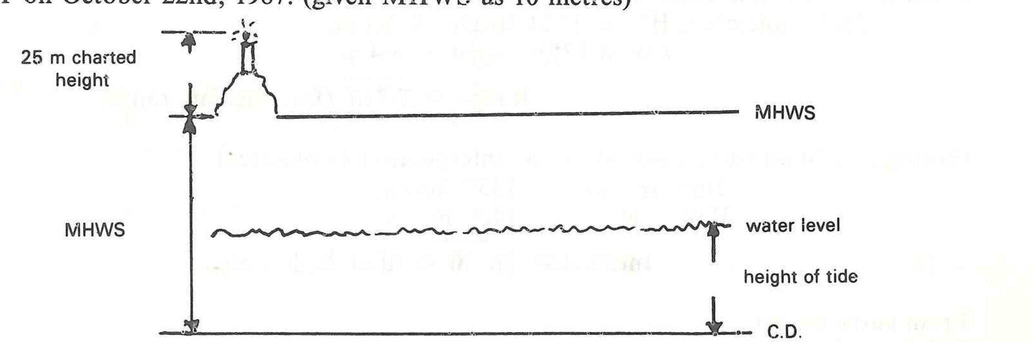


Fig. 24·14

From the pole diagram we see that we need to find the height of tide at 0845 GMT on 22nd October. This is done in the usual manner using the tide curve and tide tables.

HW 1045 hours, height 9·1 m.
LW 0515 hours, height 1·3 m.

Range 7·8 m. (Spring)

(Spring and Neap curve co-incide; so no interpolation needed)

Using curve and tide table
Height of tide = 7·1 metres above C.D.

MHWS = 10·0 m. (given in question)
Height of tide = 7·1 m. (found by calculation)
∴ Water level = (10·0 − 7·1) = 2·9 m. below MHWS

Height of light above MHWS = 25 m. (given in question)
∴ Height of light above water level = (25 m. + 2·9) = 27·9 metres.
Answer—27·9 metres.

Example 24·7—Calculate the under-keel clearance of a vessel whose draught is 15 metres at Liverpool at 1350 hours GMT on 23rd September 1987. The charted depth is 10 metres.

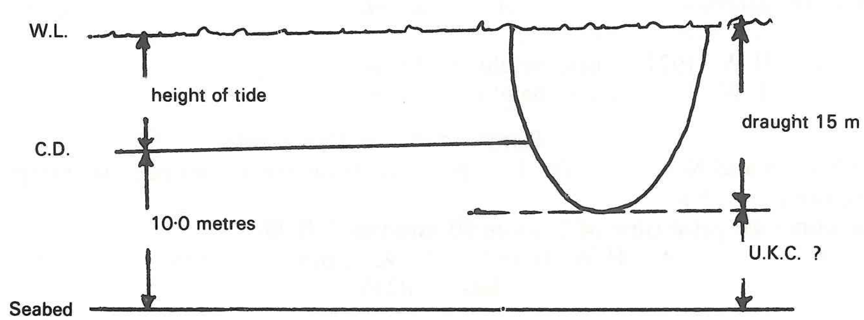


Fig. 24·15

From Tide curve and tables find the height of tide:
23rd September, HW at 1120, height = 9·1 m.
LW at 1753, height = 1·4 m.

Range = 7·7 m. (Intermediate range)

(Spring and Neap curve co-incide so no interpolation is required).
Time required = 1350 hours
HW at = 1120 hours

Interval = 2h 30 m after high water

From curve we get
Height of tide above *CD* = 6·3 metres

From the pole diagram—
Left hand side = Right hand side
Chart datum + height of tide = Draught of vesel + U.K.C.
10·0 + 6·3 = 15·0 + U.K.C.
16·3 = 15·0 + U.K.C.
U.K.C. = 16·3 − 15·0
= 1·3 m.
Answer—Underkeel clearance = 1·3 metres

Example 24·7—Find the height of tide and the correction to be made to the lead-line at Liverpool on the 13th October, 1987 at 1120 GMT.

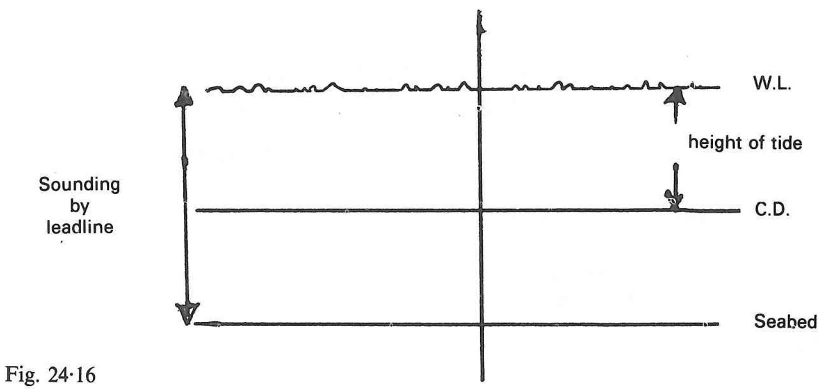


Fig. 24·16

13th October, H.W. at 1440 hours, height = 7·9 m.
L.W. at 0853 hours, height = 2·8 m.

Range = 5·1 m. (Intermediate)

(Spring and Neap curve co-incide so no interpolation can be done)
H.W. at = 1440 hours
Time given = 1120 hours

Interval = 3h 20 m (Before high water)

From curve—
Height of tide above CD = 4·8 metres

To compare the lead line sounding with the chartered depth.
Chartered depth = Sounding by lead line − height of tide. So 4·8 metres to be subtracted from lead line sounding.

Answer—4·8 metres is the correction to apply.

Example 24·8—A ship grounded off Liverpool at 1408 GMT on 5th November, 1987. Find the earliest time she could refloat.

We are given the time the ship grounded so we have to find the height of tide at that time.

5th November, H.W. at 1038 hours, height = 9·3 m.
L.W. at 1720 hours, height = 1·1 m.

Range = 8·1 m. (spring)

H.W. at 1038
Time aground 1408

Interval 0330 (After high water)

From curve,

Height of tide at 14h 08 m = 4·6 metres above CD. Since CD will remain the same we can ignore it for this calculation and now find the time when the height of the tide above CD will be 4·6 metres.

5th November, HW at 22h 54 m, height = 9·6 m.
LW at 17H 20 m, height = 1·1 m.

Range = 8·5 (spring)

From curve, time when height is 4·6 m. is 3h 11m B.H.W.

H.W. at 22h 54m
Interval 3h 11m

Time required 19h 43m

Answer—Ship will float at 1943 hours GMT on 5th November.

Exercises on Chapter 24

1. Describe the oscillation of the sea level known as the tide.
2. Define: High Water; Low Water; Range of the Tide; Duration of the Tide; Period of the Tide.
3. Define Chart Datum.
4. Distinguish between Semi-Diurnal and Diurnal Tides.
5. Discuss the Equilibrium Theory of Tides.
6. Describe the Luni-Solar Tide. Draw a graph of the luni-solar tide for the period between New Moon and the following Full Moon.
7. What is meant by: Spring Tide and Neap Tide?
8. What is the ratio between the Tide-Raising forces of the Moon and Sun? Explain why the Moon's tide-raising force exceeds that of the Sun.
9. Discuss the Progressive Wave Theory of the Tide. What is meant by Main Stream of Flood?
10. Explain priming and lagging of tides.
11. Describe the Standing Wave Theory of Tides.
12. What are Tidal Streams? Where may information of tidal streams be found?
13. Find the height of tide at Ullapool on 21st March, 1987 at 0654 hours GMT.
14. At what time GMT on the 9th March, 1987 at Ullapool on the A.M. ebb tide will the rise of tide be 2·8 metres above chart datum?

15. Calculate the underkeel clearance of a vessel whose draught is 15 metres at Liverpool at 1350 hour GMT on 23rd September, 1987. The charted depth is 10 metres.
16. A ship grounded off Liverpool at 0334 hours on 24th November, 1987. Find the earliest time she can refloat.
17. A vessel arrives off Liverpool at daybreak on the 3rd October, 1987. What is the earliest time that she can cross a bank charted as dries 1·0 m. with an underkeel clearance of 1·5 metres, if her draught is 4·2 metres?

PART 4

GENERAL ASTRONOMY

The General Astronomy dealt with in Chapters 25 to 30 inclusive, forming Part 4 of this book, serves to provide the necessary background knowledge for the study of the elements of Nautical Astronomy contained in Part 5.

CHAPTER 25

THE UNIVERSE

1. The Stars

The aggregate of all existing things, that is to say, the whole creation embracing all celestial objects and space, is known as the Universe. The universe is sometimes referred to as the Cosmos on account of its apparent perfect orderliness: the Greek word "cosmos" meaning orderly.

The materials of which the cosmos is composed is segregated into units called Island Universes or Galaxies. A Galaxy covers a vast region in which gaseous material at a very low density is interspersed with billions of Stars. Neighbouring galaxies are separated from each other by immense distances amounting to millions of Light Years, a Light Year being a unit of distance equivalent to that travelled by a light in a year. The speed of light *in vacuo* is about 186,000 miles, or 300,000,000 metres, per second, so that the Light Year is a distance of considerable magnitude. Indeed the distances between the stars within a galaxy are so great that it is difficult for us to imagine them—our minds being inadequate for such exercises.

A galaxy is bun-shaped, and the stars of which it is formed rotate about a central axis perpendicular to the plane of the greatest dimension of the galaxy. The galaxy to which the Sun belongs is known as the Local Galaxy: its diameter is about 100,000 light years and its maximum thickness is about 3,000 light years.

A star is a huge spherical body consisting of gaseous material at an exceedingly high temperature. It radiates electro-magnetic energy within a wide range of frequencies. Some stars are rendered visible through the agency of the electro-magnetic energy of optical frequency, or light, which they emit. The different temperatures of stars give rise to their distinctive colours: the hotter stars tend to be bluish whereas the cooler stars are reddish in colour.

Within the wide range of star-size and -type the Sun is not, in any way, outstanding. The Sun is a star of average size and of a type most commonly found in the universe. The Sun's pre-eminent importance to the human race stems from its proximity. It is our nearest star, and the Earth is one of the Sun's lesser family members.

When the night sky is viewed in the plane of the local galaxy the number of stars observable is considerably greater than when viewed in a direction perpendicular to the plane. The immense number of stars that may be seen on a dark clear night appear as a whitish belt stretching across the heavens. This belt is known as the Galactic Arch or, more familiarly, as the Milky Way.

Practically all the stars that are visible to the unaided eye belong to the local galaxy—other galaxies being so far away that only few of them can be seen without telescopic assistance. Island Universes appear as regions of diffuse light and, at one time, it was thought that they were clouds of inter-stellar gas within the local galaxy. For this reason they became known as Nebulae. To distinguish them from nebulous gas clouds within the local galaxy, island universes are sometimes called Extra-galactic Nebulae.

The stars because of their diverse size, type and colour, have different degrees of brightness. The actual brilliance of a star at a certain specified distance is known as the star's Absolute Magnitude. The brightness of a star relative to other stars as it appears in the eye of an observer, however, is known as the star's Apparent Magnitude. The magnitude of a star is given by a number known as its Magnitude Number. The brighter stars are said to be of low magnitude and their Magnitude Numbers are small. Magnitude Number decreases as brilliance increases. Stars which are just visible to the unaided eye are said to be of the Sixth Magnitude. Such a star is reckoned to be one hundred times less bright than a star of Magnitude One.

Now the fifth root of 100 is 2·51, so that the ratio between the brightness of stars whose Magnitude Numbers differ by unity is approximately 2½. Therefore:

A star of Magnitude 1 is 2½ times as bright as a star of Magnitude 2

A star of Magnitude 2 is 2½ times as bright as a star of Magnitude 3

A star of Magnitude 3 is 2½ times as bright as a star of Magnitude 4 and so on

Also:

A star of Magnitude 1 is $(2\frac{1}{2})^2$ times as bright as a star of Magnitude 3

A star of Magnitude 1 is $(2\frac{1}{2})^3$ times as bright as a star of Magnitude 4 and so on.

A star, the brightness of which lies between that of stars of integral magnitude numbers, has a Magnitude Number which is a decimal quantity. The star Antares, for example, has a Magnitude Number of 1·2. This means that the brilliance of Antares is less than that of a star of Magnitude 1, but exceeds that of a star of Magnitude 2. Some stars, such as for example the bright star Capella, have fractional or even negative Magnitude Numbers. The Magnitude of Capella is 0·2 and that of Sirius, the brightest of all stars not counting the Sun, is − 1·6. The Apparent Magnitudes of all navigational stars are given in the *Nautical Almanac*.

The stars visible on a dark clear night are so far distant from the Earth that their real motions are not easily detected. They are, therefore, referred to as Fixed Stars. The apparent positions of the fixed stars relative to one another change extremely slowly. Nevertheless their movements are detectable from the Star Tables of the *Nautical Almanac*.

The stars are grouped into Constellations. The astronomers of Classical Times named the constellations after mythological creatures and symbols, and many of these ancient names are still in use. Stars are named after the constellations to which they belong—the constellation name being prefixed by a letter of the Greek alphabet. Most of the brighter stars have individual names as well as constellation names. The biggest star in the constellation of Taurus—the bull is ∝ Taurus: it is also known as Aldebaran. It is important

for a nautical astronomer to be able to recognize the navigational stars. Learning the names of the stars, and being able to identify them from a knowledge of the star patterns or constellations, are fascinating, as well as rewarding, pursuits for a student of nautical astronomy.

2. The Solar System

The Solar System comprises the Sun and those celestial bodies which revolve around it and whose movements are controlled by the Sun. The principal members of the Solar System are the Sun's family of Planets. These are spherical bodies which shine by reflected light of the Sun. There are nine known planets in the Solar System. These revolve around the Sun in nearly circular Orbits, the Sun being located at the centre of the system. The orbits of the planets, in order of distance from the Sun, are illustrated in fig. 25·1.

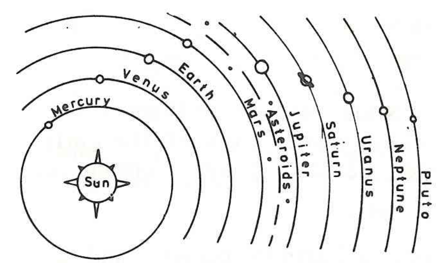


Fig. 25·1

The Sun and the planets rotate about diameters which are known as the polar axes of the bodies; and the direction of rotation, in every case is the same as that of the revolutions of the planets around the Sun.

Some of the planets have families of their own, in the form of spherical bodies called Satellites or Moons. The moons revolve around their parent planets and rotate on their polar axes in the same general direction as that of the revolution of the planets around the Sun or their rotations about their polar axes.

In addition to the planets and satellites there are large number of bodies called Minor Planets or Asteroids, the orbits of which lie mainly between those of Mars and Jupiter. Other relatively unimportant members of the Solar System include Meteors and Comets, as well as a growing number of Artificial Satellites which circle the Earth or the Sun.

The Sun is an immense sphere of gaseous material at a very high temperature. It has been estimated that the temperature of the surface material of the Sun is about 6,000° Centigrade. By observing comparatively dark patches called Sun-spots the Sun may be observed to be rotating with a period of rotation of about 24½ days.

The diameter of the Sun is about 865,000 miles and it is about 750 times as massive as the rest of the Solar System together.

The planets revolve around the Sun at different rates. The Sun's gravitational force on a planet varies inversely as the square of the distance between the Sun and the planet. The nearer is a planet to the Sun the greater is the Sun's force of attraction on it. As a result planets near to the Sun travel faster than the more remote planets; and so, by greater centrifugal force, counterbalance the attraction force of the Sun.

The following table gives details of the planets.

Name of Planet	Symbol	Mean Dist. of Planet / Mean Dist. of Earth	Periodic Time		Inclination Equator to Orbit	Mean Diameter in Miles	No. of Satellites	Orbital velocity in miles per sec.
			Days	Years				
Mercury	☿	0·3871	87·97	0·241	small	3110	—	30
Venus	♀	0·7233	224·70	0·615	unknown	7705	—	22
Earth	⊕	1·0000	365·26	1·000	23° 27′	7917	1	18
Mars	♂	1·5237	686·98	1·881	23° 59′	4207	2	15
Jupiter	♃	5·2082	4,322·59	11·682	3° 04′	86740	12	8
Saturn	♄	9·5388	10,759·20	29·457	26° 50′	71530	14 (rings)	5
Uranus	♅	19·1910	30,685·9	84·015	98° 00′	31700	5	4
Neptune	♆	30·0707	60,187·6	164·788	29° 00′	31100	2	3
Pluto	♇	39·4574	90,171·3	247·697	unknown	4000	—	2

The planets whose orbits lie within the Earth's orbit are known as Inferior Planets. There are two such planets: Mercury and Venus. The planets whose orbits lie outside the Earth's orbit are called Superior Planets: these are Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.

When a planet and the Sun lie in the same direction from the Earth the planet is said to be in Conjunction with the Sun. When a planet lies in the opposite direction to that of the Sun, that is to say, when the angle in the plane of the Earth's orbit between the planet and the Sun is 180°, the planet is said to be in Opposition to the Sun. When the angle at the Earth between the directions of a planet and the Sun is 90°, the planet is said to be in Quadrature with the Sun.

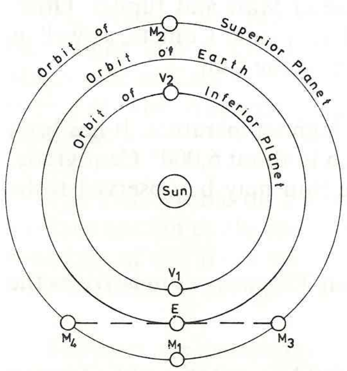


Fig. 25·2

In fig. 25·2 the Earth is assumed to be at E. When the superior planet is at position M_2 it is said to be in Conjunction with the Sun. When it is at M_1 it is in Opposition to the Sun.

It will be noticed that the inferior planet illustrated in fig. 25·2 is in Conjunction with the Sun when at position V_1 or V_2. When at V_1 it is said to be at Inferior Conjunction, and when at V_2 it is at Superior Conjunction. An inferior planet can never be in Opposition to or in Quadrature with the Sun.

The angle at the Earth between the Sun and any planet, measured in the plane of the Earth's orbit, is known as the Angle of Elongation of the planet. This angle is named East or West according to whether the planet is to the east or west of the Sun respectively. The angle of elongation of any superior planet may have a value of any angle up to and including 180° East or West. The maximum

value of the angle of elongation of an inferior planet depends upon the radius of the planet's orbit. That for Venus is about 47° and that of Mercury is about 26°.

Inferior planets appear to oscillate to and fro about the Sun, never getting very far away from the Sun. In low and middle Latitudes they are, therefore, visible for only a relatively short duration of time after sunset or before sunrise.

Planets in or near Conjunction with the Sun are above the horizon with the Sun. They are not, therefore, visible during the hours of darkness. On the other hand, planets which are in or near Opposition with the Sun are above the horizon when the Sun is below. Such planets are, therefore, suitably placed for nautical astronomical observations.

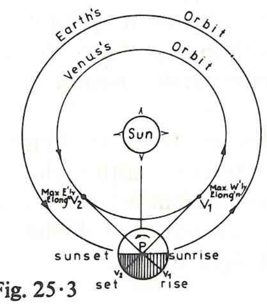


Fig. 25·3

In fig. 25·3 V_1 denotes the position of Venus when it has maximum westerly Angle of elongation. V_2 denotes Venus when it has maximum easterly elongation.

When a planet has westerly elongation it rises before the Sun and sets before the Sun. It is visible for a short period of time before sunrise but it is not visible after sunset. Because of this a planet having westerly elongation is said to be a Morning Star. When a planet has easterly elongation it rises after sunrise and sets after sunset. It is, therefore, visible in the evening after sunset but it is not visible before sunrise in the morning. Such a planet is called an Evening Star. It is interesting to note that ancient astronomers thought that Venus as an evening star was an entirely different body from Venus as a morning star. The evening star was known to the Romans as Hesperus and the morning star as Lucifer.

Because a planet is a dark body which is rendered visible only by reflected sunlight, only half of its spherical surface is illuminated at any one time. When an inferior planet is at superior conjunction, its illuminated hemisphere faces the Earth. Provided that the planet does not lie on the straight line joining the Earth to the Sun, it will appear, therefore, as a shining disc. When an inferior planet is at inferior conjunction the illuminated hemisphere faces away from the Earth. It is, therefore, invisible to terrestrial observers. Because a varying amount of a planet's illuminated hemisphere is visible at the Earth—the amount depending upon the angle of elongation of the planet—inferior planets exhibit Phases similar to the phases of the Moon.

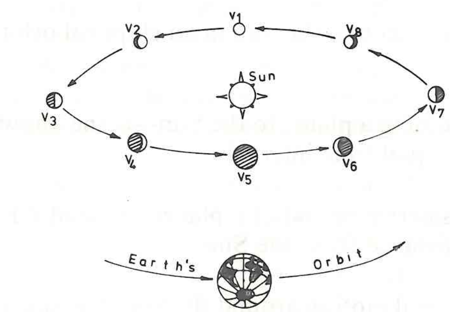


Fig. 25·4

Fig. 25·4 serves to illustrate the phases of Venus. When Venus is at V_1, it is at superior conjunction. If it is visible in this circumstance it will appear as an illuminated disc, and is said to be Full. At positions V_3 and V_7, half of its illuminated surface is visible, and its phase is said to be Half. At V_5, when it is at inferior conjunction, it is invisible at the Earth, and it is said to be New or at Change. At positions V_2 and V_8, more than half of the illuminated hemisphere is visible, and the phase is described as Gibbous. At positions V_4 and V_6 Venus appears as an illuminated Crescent. The phases of Venus may easily be observed with good binoculars or with a ship's long glass.

At New or Change Venus is about 120 million miles nearer to the Earth than when its phase is Full. Therefore Venus appears larger when it is near Change than when it is near Full. The brilliance, or magnitude, of Venus, which is the third brightest object in the heavens excelled only by the Sun and the Moon, does not change appreciably during its period of revolution around the Sun relative to the Earth. This follows from its changing phase: Venus attaining its maximum magnitude when it is near its position of maximum elongation.

Only four of the planets are suitable for nautical astronomical purposes. These are Venus, Mars, Jupiter and Saturn, which are the Navigational Planets. Mercury, although on occasions quite bright, is too near to the Sun for it to be of value to nautical astronomers. The planets Venus, Mars and Jupiter, are sometimes visible during the hours of daylight, when they are particularly valuable for position finding when out of sight of land.

3. Kepler's Laws of Planetary Motion

The famous astronomer Johannes Kepler (1571-1630) made a close study of the motion of the planet Mars relative to the background of the fixed stars. After careful observations extending over a long period of time he concluded that the orbit of Mars is elliptical and that the Sun is located at one of the focal points of the ellipse. He also observed that the orbital velocity of Mars is greatest when Mars is nearest to the Sun and least when most remote. Similar conclusions were later extended to the other visible planets, after it was discovered that they too behaved in much the same way as Mars.

From his observations and deductions, Kepler formulated his famous laws of planetary motion:

1. Every planet revolves around the Sun in an elliptical orbit having the Sun at one focus of the ellipse.
2. The straight lines joining a planet to the Sun—a line known as a radius vector—sweeps out equal areas in equal time intervals.
3. The square of the sidereal period of a planet's revolution around the Sun varies as the cube of its mean distance from the Sun.

Because of the Earth's real motion around the Sun, the Sun appears to revolve around the Earth in an elliptical orbit having the Earth at one of its foci. Observations of the Sun relative to the fixed stars, combined with gravitational theory, provides proof that the Earth revolves around the Sun.

Kepler's laws were formulated from visual observations: they were not explained mathematically until after Kepler's death. The incomparable Sir Isaac Newton (1642-1727) is credited with having provided the physical proof that the laws first enunciated by Kepler are a direct consequence of the Law of Universal Gravitation. By this law every planet is attracted by the Sun with a force known as the Solar Attraction. This force, which acts between the planet and the Sun, varies accordingly to the Inverse Square Law. This law, expressed mathematically, is: $F \propto 1/d^2$, where F is the force and d the distance between the points at which the force emanates and acts respectively. This means that if the distance d is doubled the force would be reduced to a quarter of its initial magnitude, and that if the distance were trebled, the force would be reduced to a ninth of its initial value, and so on.

Because a planet is in motion it has a tendency to fly off tangentially to its orbit. The motion of a planet in its orbit is such that Centrifugal Force, which acts radially outwards, just balances the Solar Attraction which acts radially inwards. Centrifugal Force on a planet depends upon the planet's orbital speed, so that when a planet is nearer to the Sun than its average distance, its speed is greater than its average speed, so that increased Centrifugal Force counterbalances increased Solar Attraction.

Solar Attraction and Centrifugal Force are not the only components which influence the motions of the planets. The forces of attraction exerted on a planet by the other planets and by the satellites it may have, modify the motion. The disturbances of the planets, due to these additional factors, are known as Perturbations.

The point in a planet's orbit which is nearest to the Sun is called Perihelion, and the most remote point Aphelion.

Because the Earth's orbit is elliptical, the angular diameter of the Sun varies during the course of the year. The sun is at perihelion in early January, and is at aphelion in early July. At perihelion the angular diameter is greatest and at aphelion it is least.

The Sun's apparent orbit around the Earth is an ellipse having the Earth at one of the foci. The points of nearest approach to, and most remote from, the Earth are known as Perihelion and Aphelion respectively.

The Moon revolves around the Earth in an elliptical orbit having the Earth at one of the foci of the ellipse. The points in the Moon's orbit which are nearest to, and most remote from, the Earth are known as Perigee and Apogee respectively.

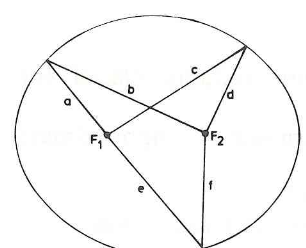


Fig. 25·5

An ellipse may be defined as a locus of points such as that of the sum of the distances from any one of these points to two fixed points is a constant quantity.

Fig. 25·5 illustrates an ellipse. Each off the fixed points F_1 and F_2 is a focus of the ellipse.

$$(a+b) = (c+d) = (e+f)$$

When the foci are close together, the ellipse is more nearly circular than when the foci are widely spaced. In the limiting cases the ellipse is a perfect circle or a straight line. In the former case the foci are coincident, and in the latter they are infinitely spaced. The ratio between the difference between the greatest and least diameters of an ellipse and the greatest diameter is known as the Ellipticity of the ellipse. The ellipticity of the planetary orbits are very small fractions: that of the Earth's orbit being about 1/80. This means that the orbits are almost circular, although for diagrammatic purposes the ellipticities of planetary orbits are often exaggerated.

Fig. 25·6 represents the orbit of a planet. The point *P*, which is the point of nearest approach to the Sun, is the planet's Perihelion. The point *A* denotes the planet when it is farthest from the Sun: this is its Aphelion. The straight line joining points of perihelion and aphelion of a planet is known as a Line of Apsides or Apse Line.

Fig. 25·7 serves to illustrate Kepler's Second Law. If the areas *ASB* and *CSD* are equal, the time taken for the planet to move from *B* to *A* is the same as that taken for it to move from *D* to *C*. Thus, the planet moves more rapidly in sweeping out arc *DC* than it does when sweeping out arc *BA*.

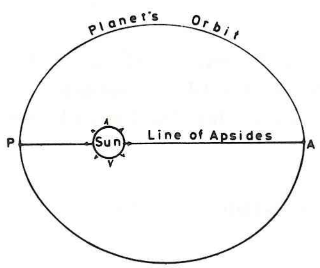
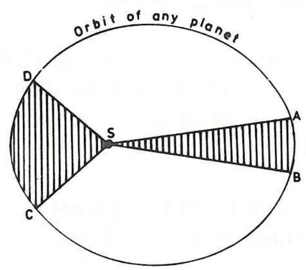


Fig. 25·6

Fig. 25·7



Exercises on Chapter 25

1. Write a short essay on The Universe.
2. Why do stars a have a variety of colours?
3. Distinguish between the terms: Absolute Magnitude and Apparent Magnitude.
4. What is meant by the statement: "The magnitude of canopus is − 0·9°"?
5. How much brighter than a star of Magnitude 7 is one of Magnitude 2?
6. The magnitude of the Sun is about − 26. How many stars of Magnitude 1 would be required to give the same illumination as that of the Sun?
7. What is a Constellation? Name ten constellations and the brightest star in each.
8. Name the Navigational Planets.
9. Define: Inferior Conjunction, Opposition, Quadrature.
10. Explain why planets in Conjunction with the Sun are not suitably placed for astronomical observation.
11. Using the data given in the Planet Table on page **188**, compute the approximate Maximum Angle of Elongation of Venus.
12. Why is the planet Mercury not suitable for nautical astronomy?
13. Explain why Venus is sometimes a Morning Star and sometimes an Evening Star.
14. Explain why and how planets exhibit phases.
15. How may a planet be distinguished from a star?
16. State Kepler's Law of Planetary Motion.
17. Explain why the nearer planets to the Sun travel faster than more remote planets.

18. Explain why the magnitude of Venus varies only slightly during its motion around the Sun relative to the Earth even so the distance between the Earth and Venus varies considerably during this period.
19. What are planetary perturbations and their causes?
20. At what time of year is the Sun's angular diameter greatest?
21. What is meant by: Perihelion, Aphelion, Perigee and Apogee?
22. Define: Line of Apsides.

CHAPTER 26

THE EARTH'S MOTIONS AND THE SEASONS

1. The Earth's Axial Motion

The Earth rotates on its axis in an anti-clockwise direction when viewed from above the Earth's North Pole. This means that all points on the Earth's surface, with the exception of the Earth's Poles, are continually being carried around the Earth's axis towards East, the Earth being said to spin on its axis from West to East.

The angular motion of the Earth on its axis causes the Sun and other celestial bodies to cross the sky, with apparent motions, from East to West. It is this apparent motion of the heavenly bodies due to the Earth's axial motion that provides the basis for the measurement of time. The time taken for the Earth to spin once on its axis is a natural unit of time called a Day.

The period of the Earth's spin relative to the Sun is known as a Solar Day, and the interval of time taken for any fixed star to make one apparent diurnal motion around the sky is a unit called a Star- or Sidereal Day.

2. The Earth's Orbital Motion

The Earth not only rotates on its axis; it also revolves around the Sun. Because of the Earth's revolution, and because of the greater distances of the stars from the Earth compared with the Sun's distance, the Solar and Sidereal Days are not equal in length. A detailed investigation into this important aspect of nautical astronomy will be made in Chapter 29 under the heading of Time.

The Earth revolves around the Sun at an average distance of 93,005,000 miles. When the Earth is at perihelion its distance from the Sun is about 91,000,000 miles: when at aphelion its distance is about 94,500,000 miles. The dates at which the Earth is at perihelion and aphelion become progressively later each year. In 1965 the Earth was at perihelion on January 4th, and at aphelion on July 4th: the corresponding dates in 1975 were January 5th and July 5th.

The time taken for the Earth to complete one revolution around the Sun provides a second natural unit of time called a Year.

In making one revolution around the Sun, the Earth makes 365¼ rotations on its axis with respect to the Sun, but exactly one more with respect to the fixed stars. There are, therefore, 365¼ Solar Days or 366¼ Sidereal Days in a year.

Given the average radius of the Earth's orbit, and the time taken for the Earth to make one revolution around the Sun, it may be verified that the average speed of the Earth in its orbit is about 18·5 miles per second.

3. The Celestial Sphere

Viewed from the Earth the celestial bodies appear to be projected onto the inside of a

transparent sphere of infinite radius. This sphere is known as the Sky or the Celestial Sphere. An observer has the impression that his own position occupies the centre of the celestial sphere; but, because of the Earth's relatively small size, and because of the relatively small distance (compared with the radius of the celestial sphere) between the Earth and the Sun, it is convenient, on occasions, to imagine the Earth's centre or even the Sun to occupy the central position of the sky.

The stars, because of their immense distances from the Earth, appear to maintain their positions relative to one another on the celestial sphere. On the other hand, the Sun and other members of the Solar System, because they are comparatively near to the Earth, and because of the Earth's orbital motion, change their positions relative to the fixed stars relatively rapidly.

As the Earth revolves in its orbit the Sun appears to move on the celestial sphere, against the background of the fixed stars, along a path which is in the same plane as the Earth's orbit. The complete annual path is a celestial great circle known as the Ecliptic.

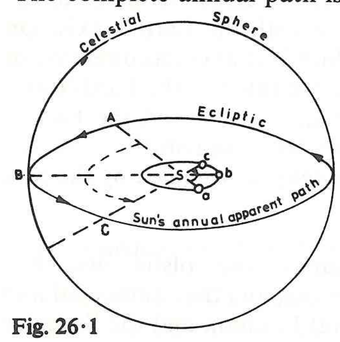


Fig. 26·1

Fig. 26·1 illustrates the celestial sphere with the Sun occupying the central position. When the Earth is at position *a* the Sun appears to be at position *A* on the celestial sphere; when the Earth is at position *b* the Sun appears to be at position *B*; and when the Earth is at position *c* the Sun appears to be at position *C*. Thus, during the interval in which the Earth moves from *a* to *b* to *c*, the Sun appears to move from *A* to *B* to *C*.

The Earth's axis is inclined to the plane of its orbit around the Sun at an angle of 66½°. Because the Earth is a rotating body it possesses a property common to all spining bodies known as Gyroscopic Inertia. Gyroscopic Inertia is a measure of the tendency of a spinning body to maintain its axis and plane of spin relative to space. The Earth tends to do this, and its axis tends to point in a fixed direction in space. The equator, therefore, tends to be permanently inclined to the plane of the ecliptic at an angle which is the complement of 66½°. The great circle on the celestial sphere which is co-planer with the Earth's equator is called the Celestial Equator. The angle between the planes of the ecliptic and the celestial equator, which is 23½° or, more accurately 23° 27′, is known as the Obliquity of the Ecliptic.

The celestial equator divides the celestial sphere into two hemispheres known, respectively, as the Northern and Southern Celestial Hemispheres.

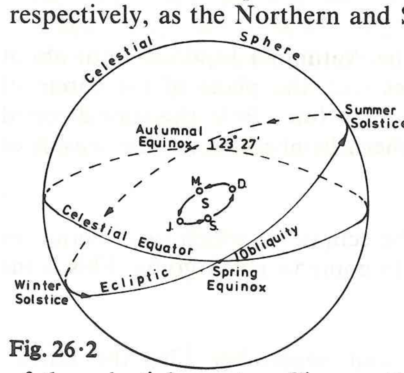


Fig. 26·2

It will be noticed in fig. 26·2 that the Sun's annual apparent path—the ecliptic—cuts the celestial equator at two diametrically opposite points. When the Earth is at position *M*, the Sun appears to cross the celestial equator from the southern into the northern celestial hemisphere. Half a year later, when the Earth is at position *S*, the Sun appears to cross the celestial equator from the northern into the southern celestial hemisphere. When the Earth is at position *J* in its orbit, the Sun is at a position in its apparent annual orbit which is most remote from the celestial equator, and to the north of the celestial equator. Six months later, when the Earth is at position *D*, the Sun is most remote from the celestial equator but to the south.

4. The Seasons

The date when the Sun, in its annual apparent orbit around the Earth, crosses from the southern into the northern celestial hemisphere (the position occupied by the Sun when the Earth is at position *M* in fig. 26·2), is about March 21st each year. On this day of the year the Earth's axis lies in the plane of a great circle on the Earth which separates the Dark from the Illuminated hemispheres of the Earth. This great circle is called the Circle of Illumination; and at every point on it the Sun will appear to be rising or setting.

On March 21st every place on Earth will be twelve hours in each of the Dark and Illuminated hemispheres of the Earth. Thus, on this day daylight and darkness have the same duration all over the Earth, and the Sun rises at 6 a.m. and sets at 6 p.m. Because day and night are equal on March 21st the point occupied by the Sun on the ecliptic on this day is called an Equinox or Equinoctial Point. From the date when the Sun occupies this equinox until about June 22nd (on which date the Earth is at position *J* in fig. 26·2), the plane of the Circle of Illuminations swings out of alignment more and more with the Earth's axis. On June 22nd the Sun is at a point in its apparent annual orbit at which it changes its direction of motion on the celestial sphere from north-going to south-going. On this day the Earth's axis is inclined at an angle of 23½° to the plane of the Circle of Illumination, and the Earth's North Pole is directed towards the Sun. The Sun then appears to "stand-still" in the sky relative to the celestial equator. For this reason the point on the ecliptic occupied by the Sun on June 22nd is called a Solstice or Solstitial Point.

The interval between the dates when the Sun is at the equinox and solstice described above is known, in the northern hemisphere, as the Season of Spring, and the equinoctial and solstitial points are known, respectively, as the vernal (or Spring) Equinox and the Summer Solstice.

From June 22nd to about September 23rd, the angle at which the Earth's axis makes with the plane of the Circle of Illumination changes from 23½° back to 0°. This interval is known, in the northern hemisphere, as the season of Summer. On September 23rd the Sun is at a point on the ecliptic similar to that at which it occupied six months earlier on March 21st. This is another equinox or equinoctial point. On September 23rd, which is the date of the Autumnal Equinox, the plane of the Circle of Illumination contains the Earth's axis and, as on March 21st, daylight and darkness all over the Earth are each twelve hours and the Sun rises at 6 a.m. and sets at 6 p.m.

The interval between the dates when the Sun is at the Autumnal Equinox until about December 22nd, the angle which the Earth's axis makes with the plane of the Circle of Illumination, increases again from 0° to 23½° with the Earth's North Pole, this time directed away from the Sun. This interval is known, in the northern hemisphere, as the season of Autumn.

At about December 22nd the Sun is at a point on the ecliptic at which its direction of motion relative to the celestial equator changes from south-going to north-going. This is the solstitial point known as the Winter Solstice.

During the six-month period between March 21st and September 23rd the Earth's northern hemisphere is directed towards the Sun. The northern hemisphere, therefore, receives more heat and light from the Sun during this half-year than does the southern

hemisphere. In the six-month period from September 23rd to March 21st the reverse is the case.

The seasons are illustrated in fig. 26·3.

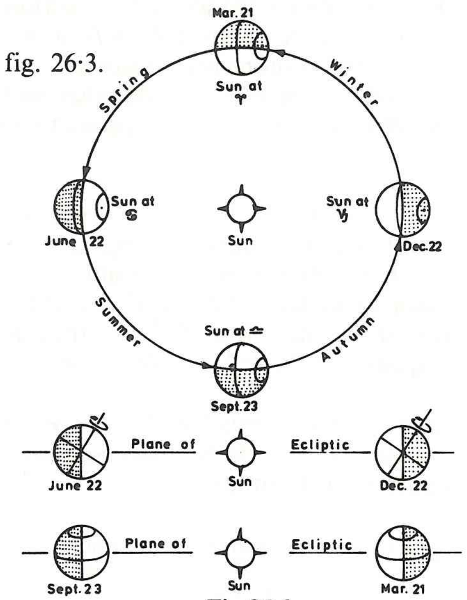
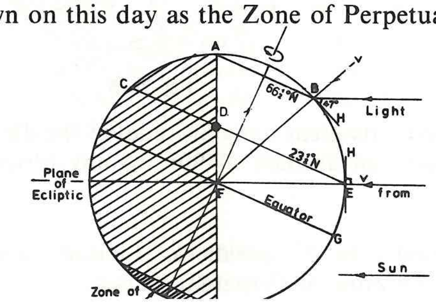


Fig. 26·3

5. Unequal Lengths of Daylight and Darkness During the Year

At about June 21st, the date of the Summer Solstice, when the Earth's North Pole is tilted directly towards the Sun, every point on the Earth located to the north of the parallel of Latitude 66½°N. experiences total daylight.

Consider an observer to be located on the parallel of 66½°N. Because of the Earth's rotation he will be carried around the Earth's axis in the direction indicated in fig. 26·4. When he is at position *A* he is on the Circle of Illumination. The Sun, therefore, is on his horizon. Twelve hours later, after the Earth has rotated through an angle of 180°, the observer will be at position *B*. During the 12-hour period the Sun will have risen to reach its greatest angular distance from the horizon. This distance—and this is easily verified from fig. 26·4—is 47°. In the 12-hour period following the instant when the observer is at position *B*, the Sun's Altitude—as the angular distance of a celestial body from the horizon is called—decreases from 47° to 0°, when the observer will again be at position *A*. During the whole of the 24-hour period the observer will have been on the illuminated hemisphere, and will have experienced daylight, for the whole day, It is evident from fig. 26·4 that the same applies to every observer located to the north of Latitude 66½°N. The polar cap bounded by this parallel of Latitude is known on this day as the Zone of Perpetual Daylight.



Now consider an observer located on the parallel of Latitude of 23½°N. The time taken for him to be carried around the Earth's axis from position *C* to *E* (refer to fig. 26·4) is clearly 12 hours. In this interval he will travel from *C* to *D* in the dark hemisphere and from *D* to *E* in the illuminated hemisphere. A moments consideration will show that, during the complete day, he is on the dark side of the circle of illumination for less than 12 hours and on the illuminated side for more than 12 hours. This applies to all observers located in the northern hemisphere.

It will be noticed in fig. 26·4 that the Sun is vertically overhead to an observer located at position *E*. This means that, in the interval during which the observer was carried around the Earth's axis from *D* to *E*, the Sun increased its altitude from 0° to 90°. It is evident that an observer on the equator experiences 12 hours' daylight and 12 hours' darkness during the course of the day. It is also evident from fig. 26·4 that the maximum altitude of the Sun at any position on the equator on June 21st is 66½° bearing North of an observer.

An observer located on the parallel of 66½°S. experiences total darkness during the whole of the day when the Sun is at the Summer Solstice. The same applies to every position to the south of that parallel of Latitude.

On June 21st all places in the southern hemisphere experience a longer period of darkness than of daylight.

At about December 22nd, the Date of the Winter Solstice, when the Earth's North Pole is tilted directly away from the Sun, every point on the Earth located to the north of the parallel of Latitude 66½°N. experiences total darkness.

From fig. 26·5 it is readily seen that on December 22nd the Sun attains a maximum altitude of 47°, at which time it bears due North, to any observer in Latitude 66½°S. On this day all places on the equator have 12 hours each of daylight and darkness. All places in the southern hemisphere experience a longer period of daylight than of darkness, and all places in the northern hemisphere experience a longer period of darkness than of daylight during the course of the day.

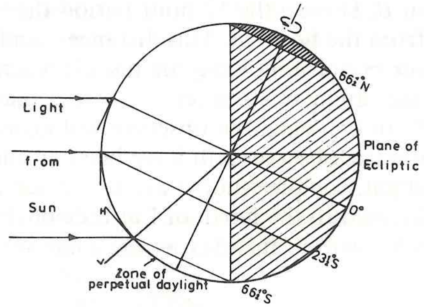


Fig. 26·5

When the Sun reaches its great daily altitude on the day of the Winter Solstice it will be vertically overhead, with an altitude of 90°, to any observer on the parallel of Latitude 23½°S.

The polar cap bounded by the parallel of Latitude 66½°N., on the date of the Winter Solstice, is known as the Zone of Perpetual Darkness.

It will be seen, by comparing figs. 26·4 and 26·5, that the length of daylight at any place on the day of the Summer Solstice is equal to the length of darkness at the same place on the day of the Winter Solstice.

At about March 21st and September 23rd, the dates respectively of the Spring and Autumnal Equinoxes, neither pole of the Earth is directed towards the Sun. The Earth's axis on these days lies in the plane of the circle of illumination, so that daylight and darkness are each 12 hours all over the Earth.

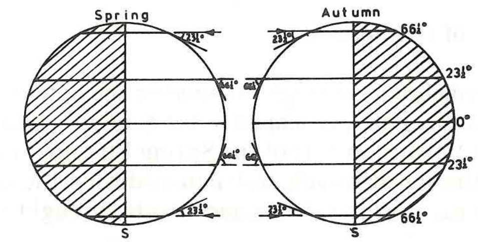


Fig. 26·6

At either equinox the altitude of the Sun at the equator reaches a maximum value of 90°. For places in other Latitudes the greatest daily altitude of the Sun is equal to the complement of the Latitude of the place. This may be verified from fig. 26·6.

6. Climatic Zones

Because of the Earth's axial tilt of 66½° to the plane of its orbit around the Sun, the altitude of the Sun at noon, which is the time of day at which the Sun attains its greatest daily altitude, varies throughout the year.

At the equator on June 21st, the date of the Summer Solstice, the Sun's noon-day altitude is 66½° bearing North of the observer. From this date to that of the Autumnal Equinox on September 23rd, the Sun's noon-day altitude increases progressively to 90°. From September 23rd to December 21st, the noon-day altitude of the Sun decreases from 90° to 66½°; but, during this period, the Sun attains its greatest daily altitude bearing South of an observer. The variation of the Sun's noon-day altitude throughout the year is similar for all Latitudes: this being 47°, or twice the obliquity of the ecliptic.

As a consequence of the changing noon-day altitude of the Sun the Earth is divided into Climatic Zones. Between the parallels of 23½°N. and 23½°S. the Sun's altitude at noon is never less than 66½°; and that, on at least one day of the year, the Sun's noon-day altitude is 90°. The spherical zone contained between these parallels of Latitude is known as the Torrid Zone. The northern and southern boundary parallels of the Torrid Zone are known, respectively, as the Tropic of Cancer and the Tropic of Capricorn. The parts of the Torrid Zone to the north and south of the equator are known, respectively, as the North Torrid and the South Torrid Zones.

The polar caps bounded, respectively, by the parallels of 66½°N. and 66½°S. are regions in which, on at least one day of the year, total daylight or total darkness is experienced. These parallels are known, respectively, as the Arctic Circle and the Antarctic Circle, and the caps which are bounded by them, are known as the North Frigid and the South Frigid Zones.

The spherical zones of the Earth which lie between the Torrid and Frigid Zones are known as the Temperate Zones—the North Temperate in the northern and the South Temperate in the southern hemisphere, respectively.

Fig. 26·7 illustrates the Earth's climatic zones.

7. Unequal Lengths of the Season

The Earth is at perihelion a fortnight or so after the date of the Winter Solstice. It will be remembered that when the Earth is nearest to the Sun its orbital speed is greatest. Thus, from the date of the Winter Solstice to that of the Spring Equinox, that is to say, during the season of northern Winter, the Earth travels faster than during the other seasons. This causes the first day of Spring in the northern hemisphere to be brought forward.

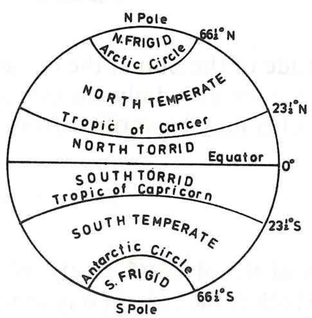


Fig. 26·7

The Summer Solstice occurs a fortnight or so before the Earth is at aphelion. The Earth, therefore, travels comparatively slowly at the time of the Summer Solstice, and during northern Summer the Earth travels more slowly than in the other sesons. This results in the first day of Autumn in the northern hemisphere being delayed.

The seasons are not, therefore, of equal length.

For the northern hemisphere:

Spring is 93 days
Summer is 94 days
Autumn is 90 days
Winter is 89 days

Because northern Winter takes place when the Earth is comparatively near to the Sun, the severity of northern Winter is mitigated. On the other hand southern Summer is warmer than it would be were the seasons of equal length.

Fig. 26·8 illustrates the unequal lengths of the seasons.

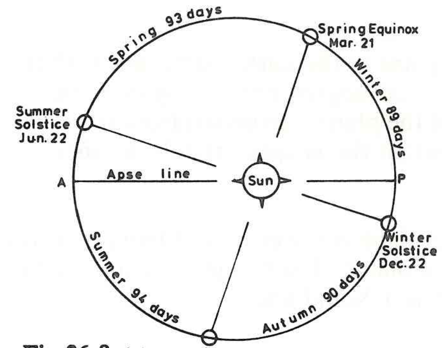


Fig. 26·8

8. The Zodiacal Belt

The Sun, in tracing out its annual apparent path across the celestial sphere, moves eastwards at the rate of 360° in a year, or about 1° per day, this motion being relative to the fixed stars. The constellations through which the Sun passes during its annual tour of the heavens are twelve in number, and they are known as the Constellations or Signs of the Zodiac.

The belt on the celestial sphere on which the Signs of the Zodiac lie extends for about 8° on each side of the ecliptic. The name given to this zone is the Zodiacal Belt.

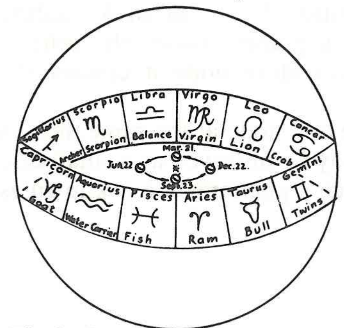


Fig. 26·9

The Ancient Egyptian astronomers are to be credited for having been the first to study, systematically, the Sun's motion relative to the background of the fixed stars. They deduced that at the time of the Spring Equinox the Sun occupied a position in the sky in the constellation of Aries the Ram. They noticed that at about 30 days later the Sun moved out of Aries and entered the constellation of Taurus the Bull, and that 30 days later the Sun entered the constellation of Gemini the Twins. For this reason we say that, on the date of the Spring Equinox the Sun is "at the First Point of Aries", and that a month later it is "at the First Point of Taurus", and so on. The Spring Equinox, therefore, is often called the First Point of Aries, and the Autumnal Equinox is called the First Point of Libra—Libra, the Balance, being the sixth Sign of the Zodiac.

At the present time, which is some five thousand years after the ancient astronomers first investigated the Sun's motion relative to the stars, the Sun is not at the First Point of Aries on the first day of northern Spring. This is the result of a phenomenon known as the Precession of Equinoxes, which we will explain in Chapter 42, which deals with the mechanical properties of Spinning bodies.

The Spring Equinox, despite the fact that it no longer coincides with the First Point of Aries, is still referred to by the latter name.

The Latin and corresponding English names of the Signs of the Zodiac are given in fig. 26·9.

The Signs of the Zodiac are easily memorized from the following ancient rhyme:

"The ram the bull, the heavenly twins,
And next the crab, the lion shines,
The virgin and the scales;
The scorpion, archer and he-goat,
The man who holds the watering pot,
And the fish with glittering tails".