of the rapid changes this value must be taken to be the LMT for the Greenwich meridian and must be corrected for longitude. The longitude correction to apply is given by:

$$\frac{\text{daily change} \times \text{longitude}}{360}$$

The longitude correction may also be obtained from Table II which is directly under Table I referred to above. After correction of the LMT the longitude in time must be applied to get the UT as for the sun.

Procedure

1. Extract the LMT tabulated for the date in question interpolating for latitude using Table I.
2. Extract the LMT for the following day if in west longitude or the preceding day if in east longitude and find the daily change.
3. Find the longitude correction from the formula above or from Table II.
4. Apply the longitude correction to the LMT in 1 normally adding if in west longitude and subtracting in east longitude. (This applies only if the times are getting later each day as is usually the case, but if not the rules must be reversed.) The result should always lie between the values found in 1 and 2.
5. Apply longitude in time +ve for west longitude and −ve for east longitude to give the UT.

Example 1

Find the UT of moonrise on 9th January to an observer in position 20° 30′ S 100° 00′ E

LMT moonrise 9th long 0	11h 17m	(interpolating for latitude
LMT moonrise 8th long 0	10h 28m	between 20 and 30)
difference	49m	
longitude correction $\frac{(49\times100)}{360}$	14m	
LMT moonrise 9th long 0	11h 17m	
longitude correction	14m	
LMT moonrise 9th long 100 E	11h 03m	
longitude in time	06h 40m	
UT	04h 23m	9th

Example 2

Find the UT of moonset on 28th June to an observer in position 33° N 170° W

LMT moonset 28th long 0	18h 25m	
LMT moonset 29th long 0	19h 21m	
difference	56m	
longitude correction $\frac{56\times170}{360}$	26m	
LMT moonset 26th long 0	18h 25m	
longitude correction	26m	
LMT moonset 26th long 170 W	18h 51m	
longitude in time	11h 20m	
UT	30h 11m	28th
=	06h 11m	29th

For the purpose of the amplitude problem there is no reason why the UT cannot be read from the chronometer at the moment when the body is seen to be rising or setting.

Procedure

1. Obtain LMT and UT of rising (or setting) from the almanac.
2. Take the declination for the time of the UT from the almanac.
3. Observe the compass bearing at the time of rising or setting.
4. Obtain the true amplitude by calculator from the formula (or from amplitude tables).
5. Convert the amplitude to a bearing and compare with the observed compass bearing.

Example 1

On 1st November in DR position 36° 10′ N 28° 20′ W at 06h 22m LMT the sun rose bearing 102° C. Find the true amplitude and the error of the compass. If the variation was 3° W find the deviation for the ship's head.

LMT sunrise 1st	06h 22m	declination 07h	14° 19.9′ S
Longitude in time	01h 53m	d corr	+0.2′
UT	08h 15m	declination	14° 20.1′ S

sine amplitude = sin 14° 20.1′ sec 36° 10′
amplitude = 17.9

true amplitude	= E 17.9° S
true bearing	= 107.9°
compass brg	= 102°
compass error	= 5.9° E
variation	= 3.0° W
deviation	= 8.9° E

Example 2

On 8th January at ship in position 30° 45′ S 166° 15′ W, the sun set bearing 240° by compass. If the variation was 6° E find the compass error and the deviation for the ship's head.

LMT sunset lat 30 S 8th	19h 06m			
diff = 12m Table I corr	+01m			
LMT sunset lat 30 45′ S	19h 07m			
longitude in time	11h 05m			
UT	06h 12m	9th Jan.	declination	22° 09.3′ S
			d corr	−0.1′
			declination	22° 09.2′ S

sin amplitude = sine declination sec latitude
sin amplitude = sin 22° 09.2′ sec 30° 45′
= 26° 01.5′

true amplitude	= W 26° S
true bearing	= 244°
compass brg	= 240°
compass error	= 4° E
variation	= 6° E
deviation	= 2° W

EXERCISE 2.3.3

1. On 30th September in DR position 20° 52′ N 153° 10′ W, the sun rose bearing 089° C. Find the error of the compass.

2. On 19th September the observed bearing by compass of sunrise was 085. DR position 39° 53′ N 51° 00′ E. Find the error of the compass and the deviation for the ship's head if the variation was 5° E.

3. On 27th June at the ship in DR position 40° 20′ S 00° 00′, the sun set bearing 301° C. Find the error of the compass and the deviation if the variation was 6° W.

4. On 18th December at a ship in DR position 38° 30′ N 32° 15′ W the sun rose bearing 126° C. Find the error of the compass.

5. On 5th January the sun set bearing 235° by gyro compass to an observer in DR position 49° 10′ S 98° 45′ W. Find the error of the gyro.

6. On 28th June the sun rose bearing 060° by gyro to an observer in position 42° 30′ N 142° 30′ W. Find the error of the gyro.

MODULE 2.4

Altitude and Azimuth. Correction of Altitudes

Definitions (see Figure 2.4.1)

Visible Horizon. This is the circle which bounds the observer's view of the earth's surface in a clear atmosphere. The range of the visible horizon will depend upon the observer's height of eye.

Sensible Horizon. This is a plane which passes through the observer's eye and is at right angles to the vertical of the observer.

Rational Horizon. This is the plane which passes through the centre of the earth and is at right angles to the observer's vertical and therefore parallel to the sensible horizon.

Zenith. The point on the celestial sphere directly above the observer.

Nadir. The point on the celestial sphere diametrically opposed to the zenith.

Vertical circle. A great circle passing through the zenith and the nadir, hence cutting the rational horizon in a right angle.

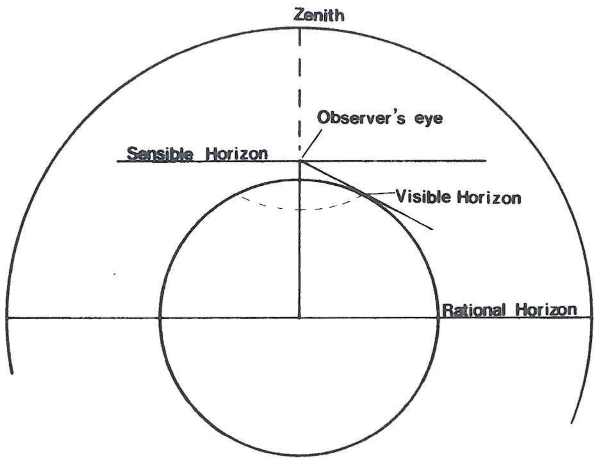

FIG. 2.4.1

The coordinates used to define a position on the celestial sphere with reference to an observer on the earth are altitude and azimuth. These can be measured by the observer, the altitude with a sextant and the azimuth with a compass.

The true altitude is defined as the angle at the centre of the earth between the plane of the rational horizon and a line joining the centre of the earth to the body. Alternatively it can be defined as the arc of a vertical circle between the body and the rational horizon. The zenith distance of the body is the arc of the vertical circle between the body and the zenith and will be equal to (90° – true altitude).

The azimuth is defined as the arc of the horizon between the vertical circle through the elevated pole and the vertical circle passing through the body. Thus the terms azimuth and bearing are stating the same thing in different ways (see Module 2.3).

The true altitude (or zenith distance) and the azimuth define the position of the body unambiguously with reference to the observer. This is referred to as the Horizon system of coordinates.

Conversion between the horizon system and the equinoctial system

The essential element of the methods of sight reduction to find the observer's position on the earth, which will be discussed in Module 2.7, is a conversion between the horizon system coordinates of altitude and azimuth and the equinoctial system of declination and hour angle (LHA). This may be done by the solution of a spherical triangle formed by the intersection of the three great circles:

(i) the observer's meridian
(ii) the meridian through the body
(iii) the vertical circle through the body.

In Figure 2.4.2 this triangle is shown as triangle PZX, P being the pole, Z the zenith of an observer in latitude 50° N and X, a body with northerly declination.

The sides of the triangle will be the observer's co-lat (90° – latitude), the co-dec of the body (90° – declination) and the zenith distance of the body.

The main object of celestial navigation is to find the observer's position. The side PZ would enable the latitude to be known and the angle P (LHA) would enable the longitude to be found from the GHA. However three parts of the triangle must be known for a solution and without knowing the observer's position only one

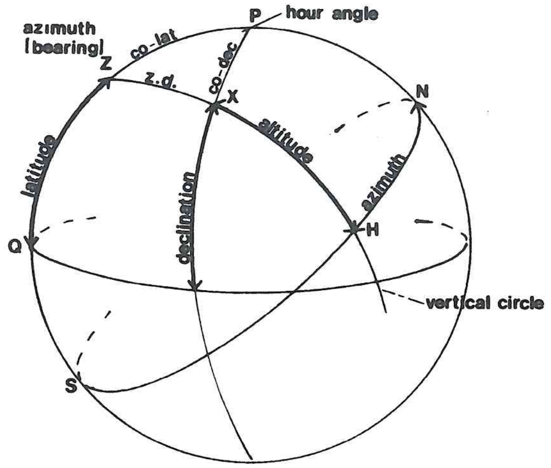

FIG. 2.4.2

part is actually known, that is the side PX or (90° – declination). However the side ZX can be measured or more correctly it can be found from the true altitude. But a third part of the triangle is still required. The azimuth can be measured with a compass but alas not with sufficient accuracy to be used for this purpose. The way in which this problem is dealt with is the subject of Module 2.7. The rest of this module is concerned with the way in which the true altitude and zenith distance are obtained from the sextant observation of a bodies altitude above the visible horizon.

Observed altitude

If an observer measures the altitude of a heavenly body he will measure the angle at his eye between a line from the eye to the body observed, and a line from the eye to the visible horizon directly beneath the body. This is referred to as the observed altitude and will be obtained from the sextant altitude with any error of the sextant allowed for (index error).

Dip

This is defined as the angle at the observer's eye between the plane of the sensible horizon and a line joining the observer's eye to the visible horizon, or alternatively the depression of the visible horizon below the sensible horizon.

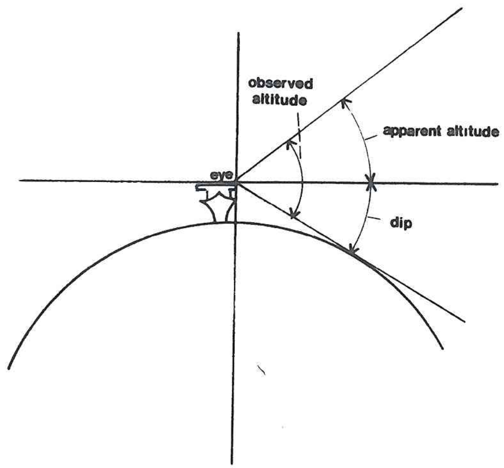

FIG. 2.4.3

The dip is subtracted from the observed altitude to give an altitude above the sensible horizon. The observed altitude corrected for dip is called the apparent altitude. This is illustrated in Figure 2.4.3.

It should be apparent from Figure 2.4.3 that:

$$\text{apparent altitude} = \text{observed altitude} - \text{dip}$$

Dip is always negative and must be applied to altitudes of all bodies. Values of dip are tabulated against height of eye in nautical tables and also in the Nautical Almanac. The table in the Nautical Almanac is usually the most convenient to use.

It should be noted that the value of the dip is affected by the amount of refraction of the observer's line of sight to his horizon. Uncertainty in the amount of refraction makes the dip correction the least accurate of all the corrections to altitude. Dip tables are based upon the formula:

$$\text{dip} = 1.77\sqrt{h} \text{ (where h is the observer's height of eye in metres)}$$

Refraction

A ray of light entering a medium of greater density than that in which it has been travelling will be bent or refracted towards the

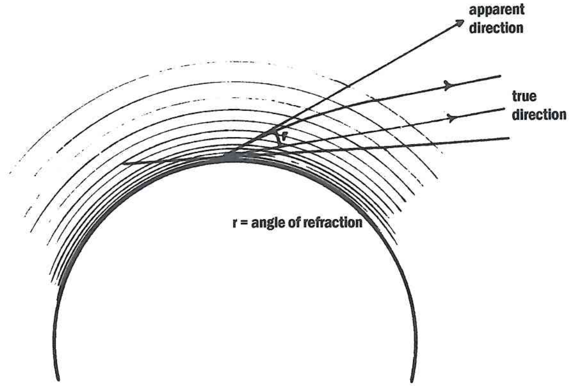

FIG. 2.4.4

normal. The normal is the perpendicular to the interface between the two mediums at the point of entry of the light.

Light entering the earth's atmosphere from the celestial body is entering a progressively more dense medium as it approaches the earth's surface. The light is therefore being continually refracted as it travels through the atmosphere. This causes the light to be coming apparently from a higher altitude than is really the case. This is shown in Figure 2.4.4. The correction for refraction is therefore negative. The refraction is greatest at low altitudes and decreases to zero when the light is entering the atmosphere at 90°, that is from the zenith. Uncertainty in the amount of refraction makes it inadvisable to take low altitude observations unless unavoidable.

Values for the refraction are tabulated against altitude in nautical tables. The correction is applied to the altitude of all bodies.

Semi Diameter

In the case of the sun and moon it is easier and more accurate to observe the altitude of the upper or lower edge or limb of the body than to observe the estimated centre of the body. A correction for the radius of the visible disc must therefore be applied to obtain the altitude of the centre of the body. This correction is called the semi diameter. The value will be the angle at the observer's eye subtended by the radius of the body. From Figure 2.4.5 it can be seen that the correction will be positive if the lower limb is observed and negative if the upper limb is observed.

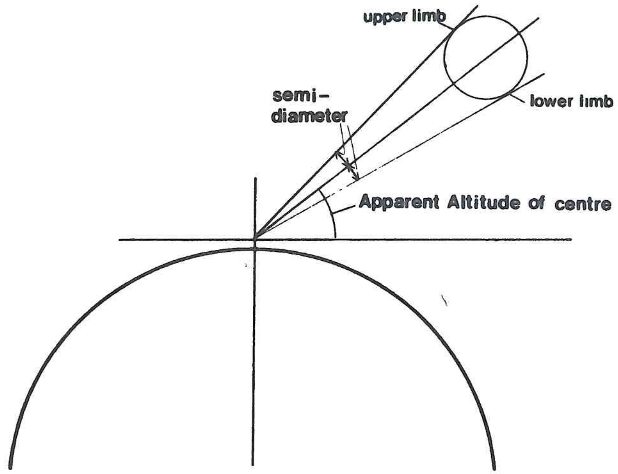

FIG. 2.4.5

Semi diameter varies as the distance of the body from the earth and therefore will change due to the elliptical orbits of the earth around the sun and the moon around the earth. Values are given in the daily pages of the Nautical Almanac at the foot of the appropriate columns. One value is given for the sun for the three days on the page, but three values are given for the moon. The values are in minutes of arc.

There is no semi diameter correction for stars or planets.

Parallax

This is defined as the angle at the centre of the body subtended by a line from the centre of the earth and a line to the observer's eye. The parallax is maximum when the body is on the sensible horizon and then is called the **Horizontal Parallax**.

The application of the parallax corrects the altitude from that which is observed at the observer's position to that which would be observed at the centre of the earth, that is the true altitude.

In Figure 2.4.6

angle CSO is the angle of parallax,
angle AOS is the apparent altitude uncorrected for parallax,
angle ACH is the altitude after correction for parallax, that is the true altitude.

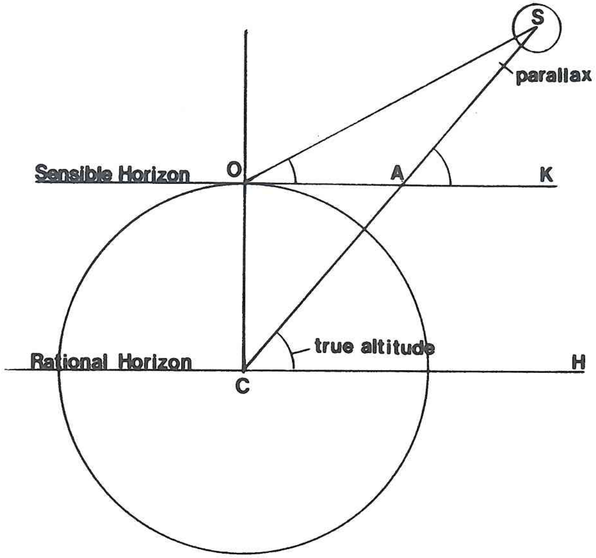

FIG. 2.4.6

Thus angle ACH = angle SAK
and angle SAK = angle CSO + angle AOS (exterior angle of a triangle is equal to the two interior and opposite angles).
Thus true altitude = apparent altitude + parallax.

The parallax correction is always positive to the apparent altitude and its value will vary with the altitude, being maximum when the body is in the horizon and zero when the body is in the zenith.

Values for the sun are tabulated against altitude in nautical tables. Parallax must be applied to altitudes of the sun and moon, although the moon's parallax requires a further correction (see correction of the moon's altitude). There is no parallax correction necessary for stars due to their great distance. Planets parallax may sometimes be negligible but sometimes be considerable, sometimes greater than the sun. A planet's minimum parallax value will occur at conjunction (superior conjunction for an inferior planet). The maximum value will occur at opposition for a superior planet and inferior conjunction for an inferior planet. The parallax correction for a planet is conveniently ignored when correcting

altitudes by individual corrections, but it is allowed for in total correction tables which will be introduced at the end of this module.

Correction of the Moon's Altitude

Due to the proximity of the moon to the earth there are two additional corrections to the moon's altitude which are negligible for other bodies and are therefore ignored.

Reduction to the moon's horizontal parallax for latitude

The horizontal parallax for the moon is given in the daily pages for each hourly entry in the column headed H.P.

This is in fact the moon's equatorial horizontal parallax, that is the angle at the moon's centre subtended by the earth's equatorial radius. The oblate shape of the earth however means that the lesser polar radius will subtend a smaller angle. Thus the parallax must be reduced for latitude. This is shown in Figure 2.4.7.

The value of the 'Reduction to the Moon's Equatorial Horizontal Parallax for Latitude' is tabulated in nautical tables against latitude. The parallax in altitude can then be found by:

Parallax in altitude = horizontal parallax × cos altitude.

The parallax in altitude is then added to the apparent altitude as for the sun.

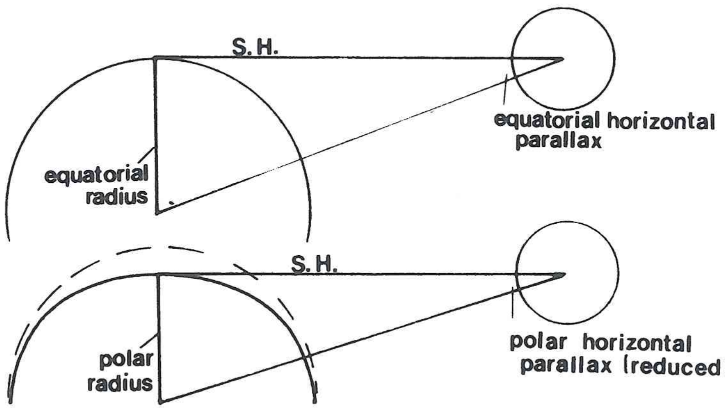

FIG. 2.4.7

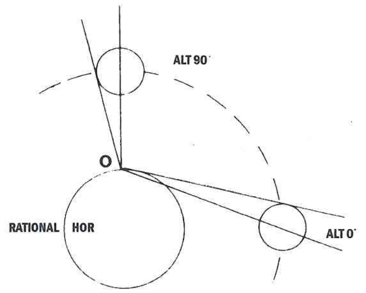

FIG. 2.4.8

Augmentation of the moon's semi diameter

The only variable which determines the semi diameter of any given body is its distance from the observer. A body will be closest to the observer when it is at his zenith, that is with altitude 90°. The distance and therefore the semi diameter decreases as the altitude decreases as illustrated in Figure 2.4.8. In the case of the sun the earth's radius is extremely small compared to the distance of the sun and therefore has a negligible effect. This is not so in the case of the moon. The values for semi diameter of the moon which are given in the almanac are for when the body is on the rational horizon, that is with altitude 0°. The Augmentation of the Moon's Semi-diameter is a positive correction to these values. The augmentation is tabulated in nautical tables against altitude.

To summarize the corrections required for the sun, the moon, the planets and stars

Sun	
sextant index error	+ve or −ve
dip	−ve
refraction	−ve
semi diameter	+ve for lower limb, −ve for upper limb
parallax	+ve
Moon	
sextant index error	+ve or −ve
dip	−ve
refraction	−ve
semi-diameter after augmentation	+ve for lower limb, −ve for upper limb
parallax after reduction of the h.p. for latitude	+ve
Stars and Planets	
sextant index error	+ve or −ve
dip	−ve
refraction	−ve

Example 1

If the sextant altitude of the sun's lower limb was 45° 20′, sextant index error 1.2′ on the arc, height of eye 15.4 metres and date 5th January, find the true altitude.

sext. alt.	45° 20.0′	
i.e.	−1.2′	
obs. alt.	45° 18.8′	
dip	−6.9′	from table in almanac
app. alt.	45° 11.9′	
refr.	−0.9′	from table in Norie's Tables
	45° 11.0′	
semi diam.	+16.3′	from almanac for 5th Jan.
	45° 27.3′	
parallax	+0.1′	from table in Norie's Tables
true alt.	45° 27.4′	

Example 2

The sextant altitude of the moon's lower limb was 36° 58.2′. Index error 0.8′ off the arc. ht. of eye 5.4 metres. Date 8th January at 1200. DR position 32° 50′ N 34° 00′ W. Find the true altitude.

sextant altitude	36° 58.2′	semi-diameter	14.9′
index error	+0.8′	augmentation	0.1′
observed altitude	36° 59.0′	semi diameter	15.0′
dip	−4.1′		
	36° 54.9′	equ. h.p.	54.8′
refraction	−1.3′	red for lat.	0.1′
	36° 53.6′	h.p.	54.7′
semi diameter	+15.0′		
	37° 08.6′	parallax in alt. 54.7′ cos alt.	
parallax in alt.	+43.7′	=43.7′	
true altitude	37° 52.3′		

Example 3
Find the true altitude of the star Rigel if the sextant altitude is 29° 17.2′, the index error 1.8′ off the arc, and the height of eye 14 metres.

sextant alt.	29° 17.2′
index error	+1.8′
observed alt.	29° 19.0′
dip	−6.6′
	29° 12.4′
refr.	−1.7′
true altitude	29° 10.7′

EXERCISE 2.4.1

Find the true altitude in the following cases using individual corrections. Answers given are worked using Burton's nautical tables.

Body	Sext. alt.	I.E.	Ht. eye	Date
1. Sun LL	52° 31.2′	2.2′ on the arc	8.3m	4th Jan.
2. Sun LL	33° 10.8′	1.0′ off the arc	12.0m	27th June
3. Sun UL	71° 53.5′	1.8′ off the arc	11.0m	20th Sept.
4. Sun UL	27° 46.7′	nil	7.7m	30th Sept.
5. Sun LL	62° 34.3′	2.2′ off the arc	9.0m	18th Dec.
6. Sun UL	55° 55.8′	1.0′ on the arc	7.4m	28th June

EXERCISE 2.4.2

Find the true altitude in the following cases using individual corrections.

Body	Sext. alt.	I.E.	Ht. eye
1. Altair	47° 29.6′	1.0′ on the arc	11.2m
2. Canopus	32° 24.2′	0.8′ on the arc	7.3m
3. Arcturus	21° 13.6′	0.4′ off the arc	11.6m
4. Polaris	47° 15.8′	1.4′ on the arc	15.3m
5. Dubhe	37° 10.4′	1.8′ on the arc	8.4m
6. Saturn	12° 17.0′	2.0′ off the arc	14.0m
7. Venus	53° 20.2′	0.6′ on the arc	7.7m
8. Jupiter	23° 14.0′	2.2′ off the arc	11.0m
9. Mars	51° 56.0′	0.4′ on the arc	17.0m
10. Venus	14° 38.2′	2.8′ on the arc	9.9m

EXERCISE 2.4.3

Find the true altitude in the following cases using individual corrections.

Body	Sext. alt.	I.E.	Ht. eye (m)	Date (UT)	Latitude
1. Moon LL	63° 12.8′	1.6′ off the arc	7.3	2200 18th Dec.	44° 56.3′ N
2. Moon LL	34° 14.8′	2.2′ on the arc	13.0	0800 30th Sept.	34° 23.0′ S
3. Moon UL	58° 16.2′	1.0′ on the arc	10.4	1900 19th Sept.	50° 00′ N
4. Moon UL	77° 51.6′	1.2′ off the arc	14.8	1500 27th June	56° 30′ N
5. Moon LL	21° 38.8′	3.4′ on the arc	11.5	0200 9th Jan.	23° 00′ S
6. Moon LL	38° 21.8′	2.4′ off the arc	9.0	1600 28th June	34° 30′ N
7. Moon UL	51° 17.0′	1.6′ on the arc	16.0	1200 19th Sept.	40° 00′ N
8. Moon LL	43° 18.4′	nil	13.7	0300 2nd Nov.	2° 00′ S

Total Correction Tables
In practice correction of altitude is simplified by the use of total correction tables, which combine individual corrections. Nautical tables contain their own versions of total correction tables but the most commonly used, and described here, are the convenient tables included in the Nautical Almanac. These are in three tables, one for the sun, one for the moon, and one for the stars and planets. Each table is compiled with the apparent altitude as the argument so that the dip correction must be first applied to the observed altitude. A dip table is included.

The dip table is tabulated against height of eye and is based upon the formula:

$$1.76\sqrt{\text{ht of eye in metres}}$$

The table is arranged as a critical entry table which means that one value of the correction is given for an interval of the argument. This means that no interpolation is required and it should be remembered that if the height of eye is a tabulated value the upper of the two figures should be extracted. Thus a height of 13.0 metres gives a dip correction of −6.3′ (see extracts from Nautical Almanac).

Sun's total correction table

The sun's correction table found on the first page of the almanac, corrects for mean refraction, semi diameter and parallax. The argument is the apparent altitude, that is the observed altitude corrected for dip. Two separate tables are used, one for the months April to September and one for the months October to March. This allows for annual variations in the semi-diameter to be allowed for. Each table contains corrections for the lower limb in bold type and corrections for the upper limb observations in feint type. The tables are arranged as critical entry tables as described for the dip table. For example an argument of 51° 08′ for the apparent altitude will give a correction of +15.5′ for the lower limb in the October to March table, while a value of 50° 46′ will give a correction of +15.4′.

Example

The sextant altitude of the sun's lower limb was 48° 56.3′. Index error 1.2′ on the arc. Height of eye 7.2 metres. Date 16th June. Find the true altitude.

sextant altitude	48° 56.3′
index error	−1.2′
observed altitude	48° 55.1′
dip	−4.7′
apparent altitude	48° 50.4′
total correction	+15.1′
true altitude	49° 05.5′

Stars and planets

The correction table for stars and planets found on the first page of the almanac, corrects for the refraction only. Again it is arranged as a critical entry table with the argument apparent altitude, that is observed altitude corrected for the dip.

Additional corrections for planets are given for some dates and for some apparent altitudes. These correct for parallax when its value cannot be considered negligible.

Example

The sextant altitude of the star Procyon was 57° 18.9′. Index error 1.0′ off the arc. Height of eye 6.5 metres. Find the true altitude.

sextant altitude	57° 18.9′
index error	+1.0′
observed altitude	57° 19.9′
dip	−4.5′
apparent altitude	57° 15.4′
total correction	−0.6′
true altitude	57° 14.8′

Example

The sextant altitude of the Venus on 1st December was 38° 06.5′. Index error 0.5′ off the arc. Height of eye 5.0 metres. Find the true altitude.

sextant altitude	38° 06.5′
index error	+0.5′
observed altitude	38° 07.0′
dip	−3.9′
apparent altitude	38° 03.1′
total correction	−1.2′
	38° 01.9′
additional correction	+0.3′
true altitude	38° 02.2′

Moon's total correction table

The moon's total correction table is found on the last pages of the almanac and is in two parts. The main correction in the upper part of the table corrects for refraction, semi diameter and parallax, using mean values. It is tabulated against apparent altitude and some interpolation is required to obtain the accuracy to within one decimal place.

The second correction allows for variations in the semi diameter and parallax, both of which depend upon the horizontal parallax. The arguments are therefore apparent altitude and horizontal parallax. Two values are given one for lower limb and one for upper limb observations. They are arranged in columns the correction being taken from the same column as that from which the main correction was taken, and against the H.P.

All corrections for the moon are additive to the apparent altitude but those for the upper limb observations have had 30′ added to them to maintain them positive. This 30′ must therefore be subtracted from the final result.

Example

The sextant altitude of the moon's lower limb was 16° 58.2′. Index error 10.8′ off the arc. Height of eye 5.4 metres. GMT 1400 on 27th June. Find the true altitude.

from the almanac H.P.	54.5′
sextant altitude	16° 58.2′
index error	+0.8′
observed altitude	16° 59.0′
dip	−4.1′
apparent altitude	16° 54.9′
main correction	+62.7′
second correction	+1.1′
true altitude	17° 58.7′

Exercises 4, 5 and 6 are the same as exercises 1, 2 and 3 but to be worked with total correction tables. Answers given have been found using the correction tables in the almanac. Small variations may be found between solutions using individual corrections and total corrections.

EXERCISE 2.4.4

Find the true altitude in the following cases using total corrections.

Body	Sext. alt.	I.E.	Ht. eye	Date
1. Sun LL	52° 31.2′	2.2′ on the arc	8.3m	4th Jan.
2. Sun LL	33° 10.8′	1.0′ off the arc	12.0m	27th June
3. Sun UL	71° 53.5′	1.8′ off the arc	11.0m	20th Sept.
4. Sun UL	27° 46.7′	nil	7.7m	30th Sept.
5. Sun LL	62° 34.3′	2.2′ off the arc	9.0m	18th Dec.
6. Sun UL	55° 55.8′	1.0′ on the arc	7.4m	28th June

EXERCISE 2.4.5

Find the true altitude in the following cases using total corrections.

Body	Sext. alt.	I.E.	Ht. eye
1. Altair	47° 29.6′	1.0′ on the arc	11.2m
2. Canopus	32° 24.2′	0.8′ on the arc	7.3m
3. Arcturus	21° 13.6′	0.4′ off the arc	11.6m
4. Polaris	47° 15.8′	1.4′ on the arc	15.3m
5. Dubhe	37° 10.4′	1.8′ on the arc	8.4m
6. Saturn	12° 17.0′	2.0′ off the arc	14.0m
7. Venus	53° 20.2′	0.6′ on the arc	7.7m
8. Jupiter	23° 14.0′	2.2′ off the arc	11.0m
9. Mars	51° 56.0′	0.4′ on the arc	17.0m
10. Venus	14° 38.2′	2.8′ on the arc	9.9m

EXERCISE 2.4.6

Find the true altitude in the following cases using total corrections.

Body	Sext. alt.	I.E.	Ht. eye (m)	Date (UT)
1. Moon LL	63° 12.8′	1.6′ off the arc	7.3	2200 18th Dec.
2. Moon LL	34° 14.8′	2.2′ on the arc	13.0	0800 30th Sept.
3. Moon UL	58° 16.2′	1.0′ on the arc	10.4	1900 19th Sept.
4. Moon UL	77° 51.6′	1.2′ off the arc	14.8	1500 27th June
5. Moon LL	21° 38.8′	3.4′ on the arc	11.5	0200 9th Jan.
6. Moon LL	38° 21.8′	2.4′ off the arc	9.0	1600 28th June
7. Moon UL	51° 17.0′	1.6′ on the arc	16.0	1200 19th Sept.
8. Moon LL	43° 18.4′	nil	13.7	0300 2nd Nov.

MODULE 2.5

Position Lines and Position Circles

One timed observation of the altitude of a heavenly body will give a position circle. There will be many positions from which the same altitude would be observed at any one time. If all these positions were joined they would form a circle on the earth's surface and this circle could be drawn around the geographical position of the body as shown in Figure 2.5.1. The radius of the circle as measured as an arc along the earth's surface is the zenith distance (90° – true altitude). To obtain a position we will need at least two observations of two different bodies so that the two position circles intersect to define the observer's position.

It is not practical to simply draw the circle or circles on a chart. The scale of the chart would have to be far too small, and such large circles would be distorted by the projection of the chart.

If one position circle is considered then although we do not know at which point on the circle the ship lies, we can say fairly confidently that it will be reasonably close to the DR position. Furthermore the area over which the ship is likely to be should be small compared to the radius of the circle (as long as the body observed is not too close to the zenith), and over this small area the curve of the position circle can be represented by a straight line without too much error. The problem becomes to find a position

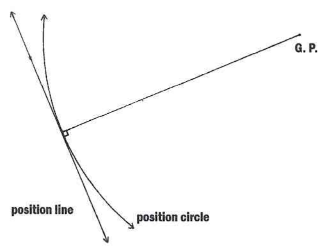

FIG. 2.5.1

through which the position line passes and the direction in which it runs at that position, so that it can be drawn on a navigator's chart and used as a position line. The direction of the position line will be perpendicular to the bearing of the body at the time of the observation which can be found as described in Module 2.3. The position through which it passes near to the DR position requires some calculation and there are various methods of obtaining this. The calculations will be dealt with in Module 2.7. Here we will concern ourselves only with the manipulation of the position lines.

The Intercept Method (Marcq St. Hilaire Method)

It may be said that the intercept method is the only method which the navigator needs to know as any observation may be worked by this method. The only case when it would not be used is the case when the body is bearing due north or due south when the calculations can be made much shorter and easier. This case will be dealt with in Module 2.6.

A position is assumed, probably the DR position but not necessarily so as long as it is reasonably close to the true position. Calculations are then made to find the zenith distance that would have been observed from that position. The bearing of the body is also calculated. If the ship was actually in the assumed position the position line could be drawn through it in a direction at right angles to the bearing. However by taking the real or true zenith distance from the observation, it will be seen whether the ship lies closer to or further away from the geographical position than the assumed position. If the true zenith distance is greater than the calculated zenith distance then the ship must be further from the geographical position than was assumed. If the true zenith distance is less than the calculated zenith distance then the ship must lie towards the geographical position from the assumed position. The difference between the true and calculated zenith distances is called the intercept and it is named either away or towards depending on the foregoing considerations.

The true position should be close enough to the assumed position that the true bearing may be taken to be the same as the calculated bearing. The calculated and the true position lines should therefore be parallel.

In practice only the true position line need be drawn. This is done by plotting the assumed position and drawing the intercept either towards or away from the body in the direction or

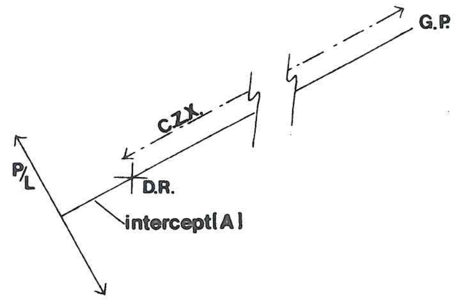

FIG. 2.5.2

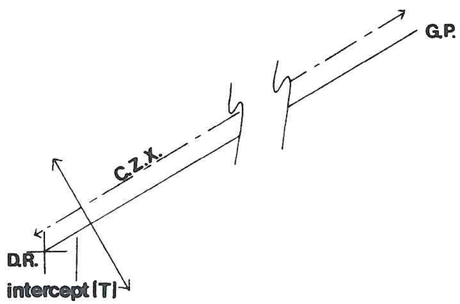

FIG. 2.5.3

reciprocal of the bearing, marking off the intercept along this line, and drawing the true position at right angles at this intercept terminal position. (ITP). Figure 2.5.2 shows a DR or assumed position with the GP. The distance between them will be the calculated zenith distance (CZX). The intercept is away (TZX greater than CZX). Similarly Figure 2.5.3 shows the intercept towards (TZX less than CZX).

It is necessary to plot only the intercept and true position line so that the plot for one observation may look like Figure 2.5.4.

If two such position lines are plotted to scale on a plotting sheet, the intersection of the two position lines can be taken to be the observed position and the latitude and longitude obtained by measuring its d'lat and d'long from the assumed position. It is sensible to use the same assumed position when calculating the two (or more) position lines.

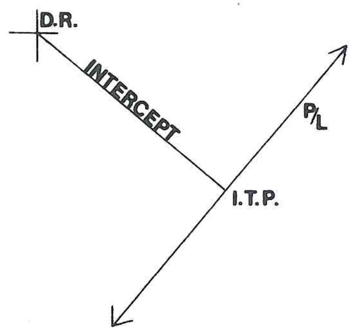

FIG. 2.5.4

To find the position by plotting the position lines of two simultaneous sights

Procedure

1. On a plotting sheet or graph paper plot a convenient point to represent the assumed position.
2. From this point draw the intercepts in the direction (if named towards), or in the opposite direction (if named away) of the respective bearings.
3. Mark off along these lines the lengths of the intercepts.
4. Through the intercept terminal positions draw the position lines at right angles to the intercepts, and mark with a small circle where the two position lines cross.
5. Measure the d'lat and the departure between the assumed position and the plotted observed position.
6. Convert departure to d'long and apply d'lat and d'long to the assumed position to obtain the observed position.

Example 1

Two simultaneous observations, when worked using an assumed position of 52° 15′ N 40° 30′ W gave the following results:

Observation 1; intercept 5.5′ away, bearing 175° T.
Observation 2; intercept 4.2′ towards, bearing 250° T.

Find the ship's observed position.
By measurement from Figure 2.5.5

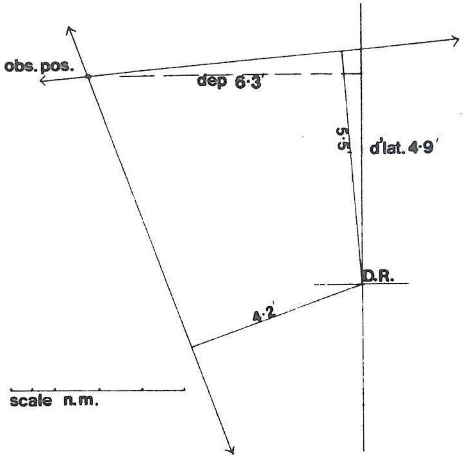

FIG. 2.5.5

d'lat $= 4.9'$ N
dep $= 6.3'$ W
d'long $= 6.3 \sec 52°\ 15'$
$= 10.3'$ W

assumed position		52° 15.0′ N		40° 30.0′ W
	d'lat	4.9′ N	d'long	10.3′ W
observed position		52° 19.9′ N		40° 40.3′ W

In practice it is usual to observe if possible at least three bodies. More if available can be used as checks. This is the practice when taking star sights at morning and evening twilight. However it is rarely possible during daylight when the sun, sometimes the moon, and occasionally a planet are the only available bodies. In these circumstances transferred position lines are used to obtain positions.

Transferring the position line

During daylight hours if there is only one body available for observation, usually the sun, a position may be obtained by using a position line from one observation and transferring it to a later time by applying a course and distance run. At this later time the sun will have changed its bearing and another position line can be obtained to cross with the transferred or 'run up' position line. The transferred position line is marked by double arrows at each end. The run up position can be used as the assumed position for the second

observation so that the two position lines can be plotted from the same position. The running up of the first position is done by calculation so that it is not necessary to plot the run.

Example 2

From an observation of a body bearing 132° T an intercept of 6.2′ towards is obtained, using an assumed position of 25° 18′ S 38° 20′ E. The ship then steamed 245° T for 45 miles when a second observation gave an intercept of 5.0′ towards bearing 205° T. The DR position obtained by running up the first assumed position by plane sailing was used to calculate the second intercept. Find the ship's position at the time of the second observation.

Run 245 by 45 miles

d'lat made good	$45 \cos 245° = 19.0'$ S
departure made good	$45 \sin 245° = 40.8'$ W
difference of longitude	$40.8 \sec 25°\ 28' = 45.2'$ W

assumed position	25° 18.0′ S		38° 20.0′ E
d'lat	19.0′ S	d'long	45.2′ W
DR position	25° 37.0′ S		37° 34.8′ E (Used as the assumed position for the second observation)

From Figure 2.5.6

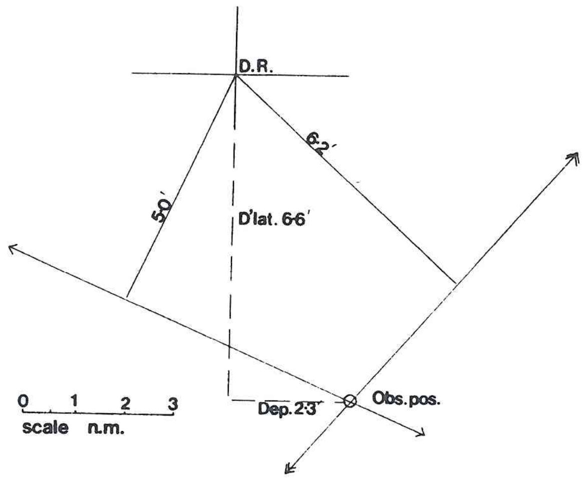

FIG. 2.5.6

between the observed position and the DR

d'lat = 6.6′ S departure = 2.3′ E d'long = 2.3 sec 25° 37′ = 2.6′ E

DR position	25° 37.0′ S		37° 34.8′ E
d'lat	6.6′ S	d'long	2.6′ E
observed pos.	25° 43.6′ S		37° 37.4′ E

Example 3

From an assumed position 32° 48′ S 15° 35′ W a body bearing 220° T was observed and an intercept of 4.8′ away was calculated. The ship then steamed 335° T for 68 miles. A second observation then gave an intercept of 2.0′ towards bearing 290° T using an assumed position of 31° 50′ S 16° 10′ W. Find the ship's position at the time of the second observation.

course = 335 d'lat = 61.6′ N departure = 28.7′ W
d'long = 28.7 sec 32° 18′ = 33.9′ W

first assumed position	32° 48.0′ S		15° 35.0′ W
d'lat	1° 1.6′ N	d'long	33.9′ W
DR position	31° 46.4′ S		16° 08.9′ W
second assumed position	31° 50.0′ S		16° 10.0′ W
d'lat	3.6′ S	d'long	1.1′ W
			dep = 1.1 cos 31° 50′ = 0.9′ W

From Figure 2.5.7

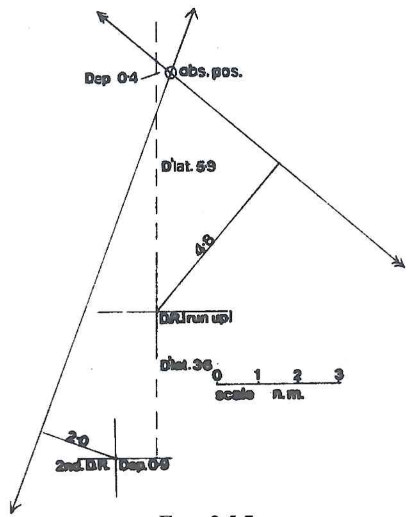

FIG. 2.5.7

between observed position and DR (run up) position:

d'lat = 5.9′ N departure = 0.4′ E d'long = 0.4 sec 31° 46′ = 0.5′

Run up position	31° 46.4′ S		16° 08.9′ W
d'lat	5.9′ N	d'long	0.5′ E
observed position	31° 40.5′ S		16° 08.4′ W

It is common practice at sea to obtain a position line during the forenoon when the sun is bearing near to east and then run this position line up to the time of noon. The transferred position line would then be crossed with a latitude by meridian altitude (see Module 2.6). At this time the sun is bearing south or north and the position line runs east-west along a parallel of latitude. The full calculations for this problem are given in Module 2.7.

Longitude by chronometer method

It has been said that the intercept method can be used for all observations out of the meridian. The alternative longitude by chronometer method of reducing a sight has been popular in the past because the problem of finding a noon position by a forenoon observation of the sun combined with a meridian altitude can be done without any plotting with slightly less work than by the intercept method. It should be noted however that the method is not suitable for bodies which are close to the meridian when the bearing is close to north or south.

An assumed latitude is used, and the longitude in which the position line cuts that parallel is calculated (see Module 2.7). This is a position through which the position line passes albeit a different position from the intercept terminal position which is obtained by the intercept method. The bearing is calculated to give the direction of the position line at right angles to it. The plotting of the position line only requires the assumed latitude and the calculated longitude to be plotted and the position line drawn through it. If two observations are obtained simultaneously it makes sense to use the same latitude for both calculations, but clearly two different longitudes will be calculated.

Procedure

1. Plot the two positions through which the position lines pass. These two positions will be on the same parallel as long as the same latitude has been used for both calculations but a different longitude will result from each calculation. The departure will

have to be obtained between the two longitudes so that they are plotted in the correct position relative to each other.

2. Draw the two positions through their respective positions in the appropriate directions.

3. Measure the d'lat and the departure between the observed position where the position lines cross and one of the other positions to obtain the latitude and longitude of the observed position.

Example 4

By using an assumed latitude of 49° 00′ N simultaneous observations of two stars gave longitudes of 9° 46.5′ W and 9° 52.4′ W bearing 135° T and 215° T respectively. Find the ship's position.

d'long between the two longitudes = 5.9′ departure = 5.9 cos 49° 00′ = 3.9′

From Figure 2.5.8

d'lat between observed position and position 49° 00′ N 9° 52.4′ W = 1.6′ S

departure = 2.3′ E

d'long = 2.3 sec 49° = 3.5′ E

position	49° 00.0′ N		9° 52.4′ W
d'lat	1.6′ S	d'long	3.5′ E
observed pos.	48° 58.4′ N		9° 48.9′ W

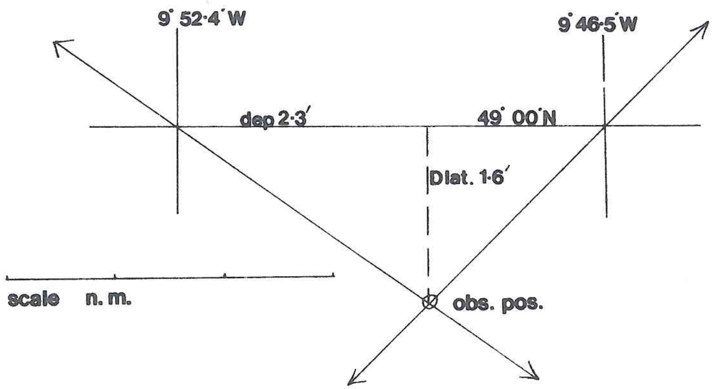

FIG. 2.5.8

Example 5

An observation of a body bearing 100° T when worked by longitude by chronometer gave a longitude of 179° 45′ E when using an assumed latitude of 10° 07′ N. The ship then steamed 095° T for 38 miles and a second observation of a body bearing 152° T gave an intercept of 4.8′ towards. The position assumed for the second observation was obtained by running up the first assumed latitude and calculated longitude by plane sailing. Find the ship's position at the time of the second observation.

Run 095° T by 38 miles
d'lat 3.3′ S departure 37.9′ E d'long 38.5′ E

first assumed latitude	10° 07.0′ N	calculated longitude	179° 45.0′ E
d'lat	3.3′ S	d'long	38.5′ E
DR position	10° 03.7′ N		180° 23.5′ E
			= 179° 36.5′ W

From Figure 2.5.9

between observed position and position 10° 03.7′ N 179° 36.5′ W and the observed position:

d'lat = 6.0′ S departure = 1.1′ W
d'long = 1.1 sec 10 = 1.1′ W

DR position	10° 03.7′ N		179° 36.5′ W
d'lat	6.0′ S	d'long	1.1′ W
observed position	9° 57.7′ N		179° 37.6′ W

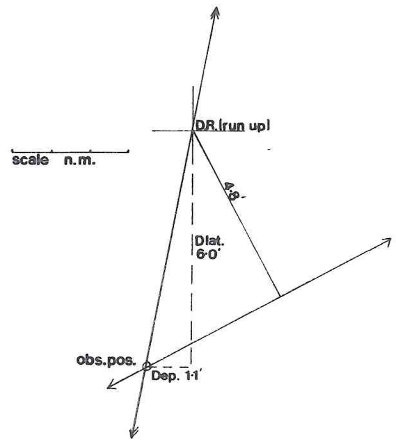

FIG. 2.5.9

Latitude by Meridian Altitude method

The meridian altitude is the altitude of the body when it is on the observer's meridian and bearing either north or south. The position line will therefore run east and west and can represent the parallel of latitude of the observer. The calculations involved to find the latitude are very quick and easy and invariably at sea the noon latitude will be obtained from the sun's meridian passage. This position line is then crossed with a transferred position line run up from an earlier sight of the sun when it was bearing to the east.

Example 7

An observation of the sun bearing 110° T during the forenoon gave an intercept of 5.5′ towards using an assumed position of 40° 15′ N 36° 40′ W. The ship then steamed 250° T for 20 miles when the latitude by meridian altitude of the sun was found to be 40° 01.5′ N. Find the ship's position at noon.

A plot of the complete problem would appear as in Figure 2.5.10. However the course and distance run is calculated and only that part of the figure inside the dotted lines would be plotted and will appear as in Figure 2.5.11.

Procedure

1. Calculate and apply the course and distance run to the assumed position used for the forenoon sight to obtain a DR for noon.

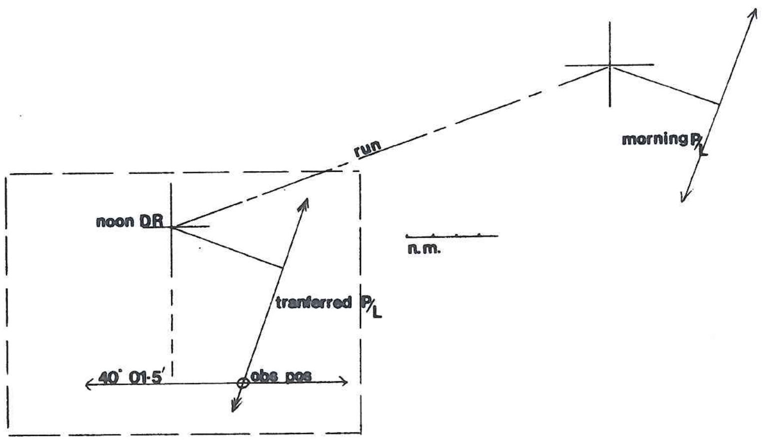

FIG. 2.5.10

2. When the latitude by meridian altitude is obtained plot the noon DR position and lay off the transferred intercept and position line from the morning observation.
3. Take the d'lat between the DR latitude and the observed latitude and plot the noon position line in the east/west direction. The observed position is where the transferred position line cuts the noon latitude.
4. Measure the departure between the DR and the observed position, convert to d'long to give the noon longitude.

forenoon assumed position	40° 15.0′ N	36° 40.0′ W
250° by 20 miles	6.8′ S	24.6′ W
noon DR position	40° 08.2′ N	37° 04.6′ W

From Figure 2.5.8

between the observed position and noon DR

departure = 3.4′ E

d'long = 3.4 sec 40° = 4.4′ E

noon DR longitude	37° 04.6′ W
d'long	4.4′ E
noon longitude	37° 00.2′ W

noon position 40° 01.5′ N 37° 00.2′ W

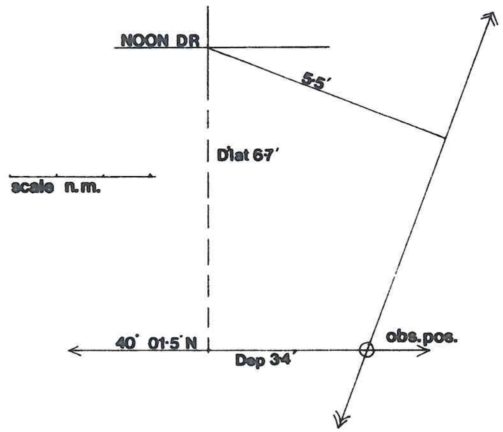

FIG. 2.5.11

Note: If this problem is done using the longitude by chronometer method for the forenoon sight then the necessity for this type of plot at noon is removed as there is a simple solution to find the longitude using the value 'C' from the computation of the bearing (see Module 2.6).

EXERCISE 2.5.1

1. From the following simultaneous observations find the observed position.
First observation intercept 6.0′ away bearing 050° T.
Second observation intercept 2.0′ towards bearing 290° T.
DR position 47° 00′ N 6° 40′ W.

2. Using assumed position 36° 05′ S 122° 15′ E, simultaneous observations were made which gave intercepts of 9.5′ away and 4.3′ towards bearing 342° T and 035° T respectively. Find the ship's position.

3. From the following simultaneous observations find the observed position.
First observation intercept 2.5′ towards bearing 175° T.
Second observation intercept 2.5′ towards bearing 270° T.
DR position 9° 30′ N 177° 50′ E.

4. From the following simultaneous observations find the observed position.
First observation intercept 1.0′ away bearing 080° T.
Second observation intercept 6.8′ towards bearing 140° T.
DR position 52° 20′ N 164° 16′ W.

5. Using assumed latitude 34° 12′ N, simultaneous observations were made which gave longitudes of 40° 27.4′ W and 40° 31.9′ W bearing 255.5° T and 140° T respectively. Find the ship's position.

6. From the following simultaneous observations find the observed position.
First observation longitude 25° 46.3′ W bearing 093° T.
Second observation longitude 25° 44.7′ W bearing 327° T.
DR latitude used 10° 14′ S.

7. From the following simultaneous observations find the observed position.
First observation gave longitude 159° 18′ W bearing 095° T.
Second observation gave longitude 159° 12′ W bearing 050° T.
DR latitude used 15° 20′ S.

8. From the following simultaneous observations find the observed position.
First observation gave longitude 146° 59′ E bearing 310° T.
Second observation gave longitude 147° 10′ E bearing 260° T.
DR latitude used 36° 40′ N.

9. From assumed position 23° 40′ N 52° 30′ W a stellar observation gave an intercept of 4.0′ towards bearing 040° T. The ship then steamed 090° T for 24 miles through a current setting 000° T. Drift experienced was 5 miles. A second observation then gave an intercept of 5.0′ towards bearing 120° T when using an assumed position obtained by applying the run and the current to the first assumed position. Find the ship's position at the time of the second observation.

10. From assumed position 6° 18′ S 42° 19′ W an observation of the sun gave an intercept of 5.6′ away bearing 130° T. The ship then steamed 145° T for 53 miles. A second observation of the moon then gave an intercept of 1.6′ towards bearing 200° T when using an assumed position obtained by applying the run to the first assumed position. Find the ship's position at the time of the second observation.

11. From assumed position 41° 10′ S 114° 00′ E an observation of venus gave an intercept of 1.0′ away bearing 100° T. The ship then steamed 100° T for 30 miles. A second observation of the sun then gave an intercept of 4.0′ away bearing 314° T when using an assumed position obtained by applying the run to the first assumed position. Find the ship's position at the time of the second observation.

12. From assumed position 19° 18′ N 160° 42′ W an observation of Jupiter gave an intercept of 4.0′ towards bearing 100° T. The ship then steamed 289° T for 34 miles. A second observation of the sun then gave an intercept of 7.0′ away bearing 200° T when using an assumed position obtained by applying the run to the first assumed position. Find the ship's position at the time of the second observation.

13. In assumed latitude 52° 50′ N an observation when worked by longitude by chronometer gave a longitude of 136° 10′ W bearing 285° T. The ship then steamed 150° T for 15 miles when a second observation using assumed latitude 52° 40′ N gave a longitude of 136° 05′ W bearing 205° T. Find the ship's position at the time of the second observation.

14. In assumed latitude 52° 20′ N an observation when worked by longitude by chronometer gave a longitude of 164° 20′ W bearing 080° T. The ship then steamed 240° T for 10 miles when a second observation using assumed latitude obtained by running up the first assumed latitude gave a longitude of 164° 29′ W bearing 140° T. Find the ship's position at the time of the second observation.

15. In assumed position 50° 24′ N 22° 26′ W a forenoon sight of the sun gave an intercept of 3.1′ away bearing 102° T. The ship then steamed 265° T for 48 miles when a latitude by meridian altitude of the sun gave 50° 21.8′ N. Find the ship's position at noon.

16. In assumed position 5° 57′ N 88° 16′ E a forenoon sight of the sun gave an intercept of 4.4′ towards bearing 121° T. The ship then steamed 088° T for 33 miles when a latitude by meridian altitude of the sun gave 5° 55.8′ N. Find the ship's position at noon.

17. In assumed position 30° 45′ N 46° 40′ W a forenoon sight of the sun gave an intercept of 6.5 towards bearing 110° T. The ship then steamed 115° T for 20 miles when a latitude by meridian altitude of the sun gave 30° 30′ N. Find the ship's position at noon.

18. An observation of a celestial body gave an intercept of 3.5′ away bearing 220° T using an assumed position of 32° 00′ S 115° 00′ E. The ship then steamed 145° T for 17 miles and then 063° T for 12 miles when a point of land in position 32° 05′ S 115° 31′ E then bore 070° T. Find the ship's position at the time of the second position line.

MODULE 2.6

Latitude by Meridian Altitude

An observation of a body when crossing the observer's meridian is of particular value to the navigator as it provides a quick and easy method of finding a position line which will run east/west near the observer's position and will therefore be coincident with the observer's parallel of latitude. At this time the altitude of a body with constant declination is maximum to a stationary observer and the observation is made by watching the altitude climb to a maximum and recording the value. A closing or opening of the declination and latitude will retard or advance maximum altitude relative to meridian passage, but this effect is often ignored. The accurate time is not required but a time to the nearest minute must be predicted beforehand in order to extract the declination and in order to know at what time to take the observations. It is common practice to take a noon observation of the sun's meridian passage and it is convenient if a star can be found whose meridian passage occurs during morning or evening twilight.

Maximum and meridian altitude

As stated above if the ship's speed and the rate of change of declination are causing the latitude and declination to close then maximum altitude will occur after meridian passage. If latitude and declination are opening then maximum altitude will occur before meridian passage. An appreciation of the magnitude of this effect is given by considering the formula:

$$\frac{15.3\,y\,(\tan \text{lat} \pm \tan \text{dec})}{60}$$

which gives the time interval in minutes between meridian and maximum altitude for a vessel steaming north or south when y is the combined change of latitude and declination. Any east or west motion of the vessel will also have an effect and modify the factor y by a small amount positive if going west and negative if going east. A vessel in latitude 60° N steaming north at 19 knots observing the sun with declination 5° S and changing south by 1.0′ per hour, will have maximum altitude 9.3 minutes before meridian passage. In latitude 20° N this would reduce to 2.3 minutes. If this is not taken into account when observing meridian altitudes then the former case will result in an error in the latitude of about 1.5′ and the latter case of less than 0.5′. In practice in the open ocean these errors are not substantial and are often ignored. On fast vessels however they should be considered and if appropriate reduced by observing the meridian altitude at the correct time of meridian passage rather than observing the maximum altitude.

Time of meridian passage

There are two methods of finding the time of meridian passage from the Nautical Almanac.

Method 1

At meridian passage, by definition the Local Hour Angle (LHA) of the body is zero. The Greenwich Hour Angle (GHA) is therefore equal to the longitude of the observer. Longitude must be expressed westerly from Greenwich as is the GHA.

GHA = W Longitude

Thus the time of the meridian passage can be found by inspection of the Nautical Almanac to find the time at which the particular GHA occurs. Care must be taken to use the correct date at Greenwich. By convention all dates given are at the ship as would be the case in practice. The date at Greenwich may be the following date if the observer's longitude is west and the preceding date if in east longitude.

Procedure

1. Write down the GHA (west longitude or (360 – east longitude)).
2. Inspect the almanac on the date in question to extract the hour when the GHA is the next value below the value in 1. Take the difference between the two values which will be the increment.
3. Inspect the increment tables to find the minutes and seconds of the time. For appropriate bodies the increment should be adjusted for the v correction if absolute accuracy is required but in practice this can be ignored.

4. The hour from 2 and the minutes and seconds from 3 give the UT of meridian passage.
5. Check that the UT with the longitude in time applied still give the correct date at the ship. If not the problem must be reworked using the preceding Greenwich date if in east longitude or the following Greenwich date if in west longitude. With practice this check can be done mentally before starting.

Example 1

Find the UT and LMT of meridian passage of the sun over the meridian of an observer in longitude 50° 14′ W on 5th January.

GHA = W longitude	50° 14.0′
For UT 15h on 5th GHA	43° 40.1′
difference (increment)	6° 33.9′

from sun increment tables 6° 33.9′ corresponds to an increment of 26m 15s

UT mer pass.	15h 26m 15s 5th Jan.
longitude in time	3h 20m 56s
LMT for long 50° 14′ W	12h 05m 19s 5th Jan.

Example 2

Find the UT and LMT of meridian passage of the moon over the meridian of 168° 30′ E on 19th December.

GHA = W longitude	191° 30.0′	
GHA for UT 20h on 18th	184° 37.6′	v = 11.3
difference	6° 52.4′	
'v'	–5.4′	
increment	6° 47.0′	

from increment tables increment = 28m 26s

GHA meridian passage	20h 28m 26s 18th Dec.
longitude in time	11h 14m 00s
LMT for longitude 40° 38′ E	31h 42m 26s
=	07h 42m 26s 19th Dec.

Notes:

1. The longitude in time added to the UT for E longitude was going to produce a change in date. The previous date at Greenwich was therefore used.

2. In practice the 'v' correction may be ignored and this will not produce any significant error. To get the time to the nearest second however it must be applied in the opposite way to that when taking out the GHA.

Example 3
Find the UT and LMT of meridian passage of the star Aldebaran over the meridian of 150° 30′ W on 31st October.

GHA star	150° 30.0′
	360°
	510° 30.0′
SHA star	290° 57.8′
GHA ♈	219° 32.2′
GHA♈ 12h 31st	219° 22.7′
difference = increment	0° 09.5′
from Aries increment table	increment = 0m 40s
UT meridian passage	12h 00m 40s 31st Oct.
longitude in time	10h 02m 00s
LMT for 150° 30′ W	01h 58m 40s 31st Oct.

Note: For a star the SHA must be subtracted from the GHA to get GHA Aries.

Method 2
The daily pages of the Nautical Almanac give times to the nearest minute for meridian passage of the sun, moon, planets, and the first point of Aries. The sun's and the moon's meridian passage is given in a box at the lower right of the right hand page once for each day on the page. For the planets it is given in a box at the lower right hand corner of the left page, once for the three days, and for Aries at the foot of the Aries GHA column. These times are local mean times and require correction for longitude to give the UT.

Sun
The values given under the heading 'Sun mer pass.' vary between 1144 and 1216 and may be taken to be the LMT of meridian passage of the sun across any meridian. The difference between the figure given and 1200 will be the Equation of Time to the nearest minute. The UT of the sun's meridian passage may very quickly be found by applying the longitude in time to this figure.

The examples that were used for Method 1 will be repeated here.

Example 1
Find the UT and LMT of meridian passage of the sun over the meridian of an observer in longitude 50° 14′ W on 5th January.

From almanac for 5th LMT mer pass.	1205
longitude in time	0321
UT meridian passage	1526

The time to the nearest minute is acceptable considering the moderate rate of change of declination of the sun, and is clearly quicker and easier than Method 1.

Moon
The LMT of meridian passage of the moon is given once for each day at the foot of the right hand daily page for upper and lower meridian passages. It will be seen that the times given get later each day by an average of about 50 minutes. The figures given must be taken to apply only to the Greenwich meridian and a longitude correction which is a proportion of the daily retardation must be applied, that proportion being the longitude divided by 360°.
Thus

$$\text{longitude correction} = \frac{\text{daily retardation} \times \text{longitude}}{360}$$

Any meridian in easterly longitude will pass beneath the sun before the meridian of Greenwich. In this case the daily retardation is taken as the difference between meridian passages on the day in question and the previous day, and the longitude correction is negative. For a meridian in westerly longitude the daily retardation is taken as the difference between meridian passages for the day in question and the following day, and the correction is positive. The longitude correction is tabulated in the Nautical Almanac under the name of Table II on the penultimate page of the almanac. Tabulation is against longitude and daily retardation. It must however be quicker to obtain the solution from a calculator using the above formula.
The correction will give the LMT for the observer's meridian. After correction the longitude in time is applied in the usual way to obtain the UT.

Procedure

1. Write down the time of the moon's meridian passage for the day in question.
2. Under this write the time of the preceding meridian passage if in east longitude or the following meridian passage if in west longitude. Note that as there is more than 24 hours between meridian passages the two times written down do not necessarily occur on consecutive dates.
3. Take the difference between the two meridian passage times and calculate the longitude correction by:

$$\text{correction} = \frac{\text{longitude} \times \text{difference}}{360}$$

4. Apply the longitude correction to the LMT of meridian passage for the day in question positive if in west longitude and negative if in east longitude (the result must lie between the two times extracted).
5. Apply the longitude in time to obtain the UT.

Example 2

Find the UT and LMT of meridian passage of the moon over the meridian of 168° 30′ E on 19th December.

LMT meridian passage for longitude 0° on 19th Dec.	0806
LMT meridian passage for longitude 0° on 18th Dec.	0717
difference = retardation	49m

$$\text{longitude correction} = \frac{49 \times 168.5'}{360} = 23\text{m}$$

LMT meridian passage for longitude 0° on 2nd Nov.	0806
longitude correction	23
LMT meridian passage for longitude 168° 30′ E	0743
longitude in time	1114
UT meridian passage longitude 168° 30′ E	2029 18th Dec.

Planets

The LMT of meridian passage for the four navigational planets are given at the foot of the left hand page in the almanac. One figure is given for the three days for each planet referring to the middle day on the page. Again this is an LMT for the Greenwich meridian and theoretically a longitude correction should be applied. However the amount of change over a day is never more

than a few minutes and the rate of change of declination of the planets is small. Any error by not applying the longitude correction will be negligible and the correction may be ignored. It only remains to apply the longitude in time to obtain the UT.

Example 3

Find the UT and LMT of meridian passage of the planet Mars over the meridian of 165° 15′ E on 31st October.

LMT meridian passage Mars 31st	2000
longitude in time	1101
UT meridian passage Mars	0859 31st

Stars

The time of meridian passage of a star is required only to enable the navigator to know when to commence his observations. The declination of a star remains constant over long periods and therefore extreme accuracy in the time of meridian passage is not required.

The LMT of the meridian passage of the First Point of Aries is given at the foot of the Aries column in the almanac. This will always get approximately four minutes earlier each successive day. The time given refers to the middle day of the page and the time for the first day can be found by adding four minutes and that for the third day by subtracting four minutes. The longitude correction will never exceed two minutes and can be ignored.

A star will cross any meridian earlier than Aries by the amount of its SHA in time. Strictly speaking this should be calculated by:

$$\frac{\text{SHA}}{15°\ 02.5'}$$

as 15° 02.5′ is the hourly rotation of the earth. No significant error will be caused if 15° is used.

Example 4

Find the UT and LMT of meridian passage of the star Aldebaran over the meridian of 150° 30′ W on 31st October.

LMT meridian passage ♈ 31st	2121 (2117 + 4 minutes)
SHA in time	1924
LMT meridian passage star	0157
longitude in time	1002
UT meridian passage star	1159 31st

To find if any stars will cross the observer's meridian during the period of twilight

If the SHA of the celestial meridian of the observer is found for the beginning of twilight and also for the end of twilight, then any star with an SHA between the two values will cross the observer's meridian during twilight and can be observed as part of star sights.

Example

Find any stars which will cross the meridian of 161° W during the period 1712 to 1750 LMT on 31st October.

LMT beginning of twilight	1712
longitude in time	1044
UT beginning of twilight	0356 1st November

GHA ♈ 03h	84° 59.6′
increment 56m	14° 02.3′
GHA ♈ 0356	98° 01.9′
GHA star = W'ly long	161° 00.0′
SHA star	62° 58.1′ will cross meridian at 1712

At 1750, that is 38 minutes later the earth will have rotated through:

$$\frac{38 \times 15^\circ\ 02.5'}{60} = 9.5 \text{ approximately}$$

Hence at 1750 the meridian of SHA 62° 58.1′ – 9° 30′ will cross the observer's meridian.

Thus between 1712 and 1750 any stars with SHA between 62° 58.1′ and 53° 28.1′ will cross an observer's meridian in 161° W.

By inspection of the almanac the star Peacock with SHA 53° 31.1′ and the star Altair with SHA 62° 15.7′ will be suitable.

Finding the Latitude

When a celestial body is on the observer's meridian then the three arcs which represent declination, zenith distance and latitude are all measured along the same meridian, in other words the meridians of the observer and the body are coincident. In this case there is a simple relationship between declination, zenith distance and latitude, which enables the unknown, the latitude to be found. The relationship is shown in Figure 2.6.1.

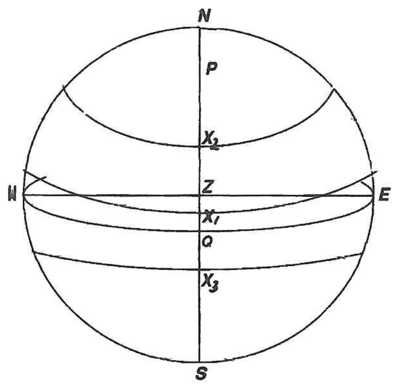

FIG. 2.6.1

In Figure 2.6.1.

Z is the observer's zenith.
WQE is the equinoctial.
ZQ represents the observer's latitude.
NS is the observer's meridian.
P is the elevated pole.
X_1, X_2 and X_3 are three bodies which are on the observer's meridian.

X_1 has declination the same name as the latitude but less than the latitude, and its zenith distance is ZX_1, and declination QX_1.

X_2 has declination the same name and greater than the latitude, and its zenith distance is ZX_2, and declination QX_2.

X_3 has declination of opposite name to the latitude, and its zenith distance is ZX_3 and declination QX_3.

From Figure 2.5.1 it can be seen that:

for body X_1 the latitude will be given by:

$$ZQ = ZX_1 + QX_1 \quad \text{(latitude = zenith distance + declination)}$$

for body X_2 the latitude will be given by:

$$ZQ = QX_2 - ZX_2 \quad \text{(latitude = declination – zenith distance)}$$

for body X_3 the latitude will be given by:

$$ZQ = ZX_3 - QX_3 \quad \text{(latitude = zenith distance – declination)}$$

These circumstances and results are difficult to remember but may easily be deduced in each problem as shown in the following examples.

Procedure

1. Find the time of meridian passage of the body and extract the declination from the almanac.
2. Correct the sextant altitude to true altitude and subtract from 90° to give the zenith distance.
3. Deduce and apply the appropriate formula to give latitude.

Example 1

On 18th December the sextant altitude of the star Diphda whilst on the meridian bearing south was 46° 15.4′. Index error 1.4′ on the arc. Height of eye 12 metres. DR position 25° 33′ N 33° 52′ W. Find the latitude and the direction of the position line.

Sextant altitude	46° 15.4′
index error	−1.4′
observed altitude	46° 14.0′
dip	−6.1′
apparent altitude	46° 07.9′
total correction	−0.9′
true altitude	46° 07.0′
	90°
zenith distance	43° 53.0′
declination	17° 58.0′ S
latitude	25° 55.0′ N

position line was 090/270

Notes: No time for the meridian passage was necessary because the declination is the same for the three days on the daily page.

The Figure 2.6.2 was drawn to represent a small sketch of the meridian as shown in Figure 2.6.1 in order to establish the

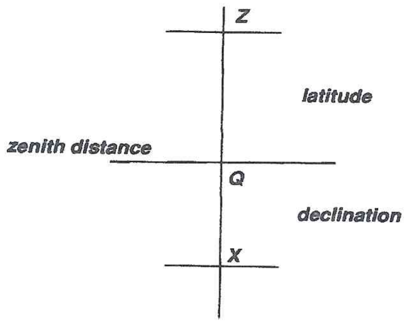

FIG. 2.6.2

appropriate rule to apply to find latitude. If the point Q is inserted first to represent the point on the equinoctial where it crosses the observer's meridian, the point X can be inserted, but it must be to the south of Q because the declination is south. The point Z representing the observer's zenith can then be inserted. This must be to the north of X because the bearing of the body was south when it was on the meridian. The point Z must also be to the north of Q because the zenith distance was more than the declination. Hence Z is to the north of Q denoting that the latitude is north and equal to (zenith distance – declination).

Example 2

On 5th January the sextant altitude of the star Fomalhaut whilst on the meridian bearing south was 77° 52.4′. Index error 3.0′ off the arc. Height of eye 11 metres. Find the latitude and the direction of the position line.

Sextant altitude	77° 52.4′
index error	+3.0′
observed altitude	77° 55.4′
dip	−5.8′
apparent altitude	77° 49.6′
total correction	−0.2′
true altitude	77° 49.4′
	90°
zenith distance	12° 10.6′
declination	29° 36.7′ S
latitude	17° 26.1′ S

position line was 090/270

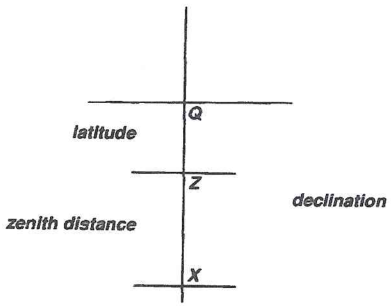

FIG. 2.6.3

Note: The diagram was drawn in the same way as for the previous example but because the zenith distance was less than the declination, Z, the zenith, must lie to the south of Q giving a south latitude.

EXERCISE 2.6.1

1. On 19th September the sextant altitude of the star Aldebaran on the meridian was 71° 22.8′. Index error 1.4′ off the arc. Height of eye 14.5 metres. The star was bearing south. Find the latitude and the direction of the position line.

2. On 19th December the sextant altitude of the star Dubhe on the meridian was 28° 06.2′. Index error 0.6′ on the arc. Height of eye 15.3 metres. The star was bearing north. Find the latitude and the direction of the position line.

3. On 5th January the sextant altitude of the star Regulus on the meridian was 28° 14.4′. Index error 1.4′ off the arc. Height of eye 14.4 metres. The star was bearing north. Find the latitude and the direction of the position line.

4. On 20th September the sextant altitude of the star Rigel on the meridian was 71° 22.8′. Index error 0.4′ on the arc. Height of eye 14.5 metres. The star was bearing north. Find the latitude and the direction of the position line.

5. On 27th June the sextant altitude of the star Alioth on the meridian was 34° 03.5′. Index error 1.8′ off the arc. Height of eye 12.0 metres. The star was bearing north. Find the latitude and the direction of the position line.

In the following examples using the sun and the moon, the time of meridian passage must first be found to obtain the declination.

Example 3
On 18th December in DR longitude 154° 20′ W the sextant altitude of the sun's lower limb when on the meridian bearing south was 44° 20.8′. The index error of the sextant was 0.4′ off the arc. Height of eye 15.3 metres. Find the latitude and the direction of the position line.

LMT meridian passage	11h 56m
longitude in time	10h 17m
UT meridian passage	22h 13m
declination	23° 23.7′ S

sextant altitude	44° 20.8′
index error	+0.4′
observed altitude	44° 21.2′
dip	−6.9′
apparent altitude	44° 14.3′
total correction	+15.3′
true altitude	44° 29.6′
	90°
zenith distance	45° 30.4′
declination	23° 23.7′ S
latitude	22° 06.7′ N

position line runs 090/270 through 22° 06.7′ N 154° 20′ W

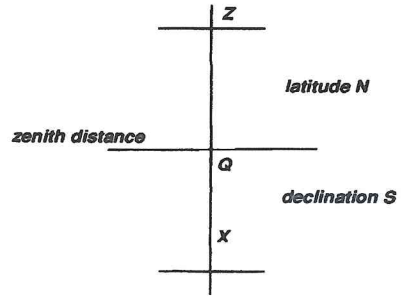

FIG. 2.6.4

EXERCISE 2.6.2

1. On 18th December in DR position 00° 20′ N 162° 20′ W the sextant altitude of the sun's lower limb when on the meridian was 66° 10.4′ bearing south. Sextant index error was 1.2′ on the arc. Height of eye 13.2 metres. Find the latitude and the direction of the position line.

2. On 28th June in DR position 25° 10′ S 40° 20′ W the sextant altitude of the sun's lower limb when on the meridian was 41° 26.4′ bearing north. Sextant index error was 2.4′ off the arc. Height of eye 7.3 metres. Find the latitude and the direction of the position line.

3. On 6th January in DR position 51° 30′ S 96° 35′ W the sextant altitude of the sun's upper limb when on the meridian was 61° 25.0′ bearing north. Sextant index error was 1.4′ on the arc.

Height of eye 11.5 metres. Find the latitude and the direction of the position line.

4. On 30th September in DR position 36° 55′ N 165° 30′ E the sextant altitude of the sun's lower limb when on the meridian was 50° 11.8′ bearing south. Sextant index error was 1.6′ off the arc. Height of eye 14.0 metres. Find the latitude and the direction of the position line.

5. On 19th September in DR longitude 141° 10.8′ E the sextant altitude of the sun's lower limb when on the meridian was 36° 37.6′ bearing 000° T. Sextant index error was 1.6′ off the arc. Height of eye 13.0 metres. Find the latitude and the direction of the position line.

Example 4

On 27th June in longitude 58° 45′ W the sextant altitude of the moon's lower limb was 67° 48.6′ to the north of the observer. The sextant index error was 2.0′ off the arc and the height of eye 9.5 metres.

LMT meridian passage 27th for longitude 0	10h 08m
LMT meridian passage 28th for longitude 0	10h 57m
difference	49m

correction for longitude $\frac{49 \times 58° 45'}{360°} = 8m$

LMT meridian passage 27th for longitude 0°	10h 08m
longitude correction	8m
LMT meridian passage for longitude 58° 45′ W	10h 16m
longitude in time	3h 55m
UT meridian passage for longitude 58° 45′ W	14h 11m 27th

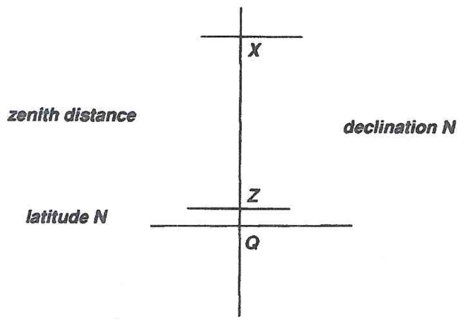

FIG. 2.6.5

declination	23° 06.9′ N H.P. 54.5
'd' corr	+1.3′
declination	23° 08.2′ N

sextant altitude	67° 48.6′
index error	+2.0′
observed alt.	67° 50.6′
dip	−5.4′
apparent alt.	67° 45.2′
main corr.	+32.1′
2nd corr.	2.9′
true altitude	68° 20.2′
zenith distance	21° 39.8′ N
declination	23° 08.2′ N
latitude	1° 28.4′ N

position line runs 090/270 through 1° 28.4′ N 58° 45′ W

EXERCISE 2.6.3

1. On 5th January in DR longitude 45° 20′ E the sextant altitude of the moon's lower limb when on the meridian was 40° 18.5′ bearing south. Sextant index error was nil. Height of eye 5.5 metres. Find the latitude and the direction of the position line.

2. On 19th September in DR longitude 162° 45′ W the sextant altitude of the moon's upper limb when on the meridian was 30° 30.5′ bearing north. Sextant index error was 1.5′ on the arc. Height of eye 10 metres. Find the latitude and the direction of the position line.

3. On 19th December in DR longitude 130° E the sextant altitude of the moon's upper limb when on the meridian was 70° 30′ bearing north. Sextant index error was nil. Height of eye 9.0 metres. Find the latitude and the direction of the position line.

4. On 30th September in DR longitude 0° the sextant altitude of the moon's lower limb when on the meridian was 68° 18.6′ bearing south. Sextant index error was nil. Height of eye 8.6 metres. Find the latitude and the direction of the position line.

Computing the sextant altitude of a star when on the meridian

If it is required to observe the meridian passage of a star then not only is it necessary to find the time when the star is on the meridian, in order to know when to commence observation, but it is advisable to know the approximate sextant altitude to set on the sextant to facilitate finding the star. It should be realised that this applies to all star observations. If the navigator waits until he can find a star with his naked eye the horizon will be too dark to observe (at evening twilight). At morning twilight by the time it is light enough to see the horizon then it will be difficult to see the constellations and find and identify a star.

In this example the time of meridian passage is found and then the altitude correction worked backwards from true altitude to sextant altitude. This altitude can then be set on the sextant and the star found in the star telescope.

Example

Compute the sextant altitude and find the LMT when the star Aldebaran is on the meridian to an observer in DR position 55° 18′ N 142° 10′ W on 19th September. Sextant index error 0.6′ off the arc. Height of eye 13.3 metres.

At meridian passage GHA = W'ly longitude

GHA star	142° 10.0′	
SHA star	290° 58.1′	
GHA ♈	211° 11.9′	
GHA 14h 19th	208° 03.8′	
increment	3° 08.1′ = 12m 30s	
UT mer pass star		14h 12m 30s 19th
longitude in time		9h 28m 40s
LMT mer pass star		04h 43m 50s 19th

Latitude	55° 18.0′ N
declination	16° 31.1′ N
zenith distance	38° 46.9′ bearing south

true altitude	51° 13.1′
total corr.	+0.8′
apparent alt.	51° 13.9′
dip	+6.4′
observed alt.	51° 20.3′
index error	−0.6′
sextant altitude	51° 19.7′

Note: All the altitude correction are applied with reversed sign.

Lower Meridian Passage

The apparent daily motion of any celestial body is to describe a circle around the celestial pole, once in a sidereal day. During this period the body will not only cross the observer's meridian but will also cross the observer's anti-meridian. (The meridian 180° removed in longitude from the observer.). Under certain circumstances the body will remain visible during the whole period, never setting below the horizon. Such a body is called a circumpolar body. The condition for circumpolarity is that the latitude is greater than the polar distance (90° − declination).

A circumpolar body will therefore be visible when it crosses the observer's anti-meridian, this occurrence being called 'lower meridian passage' or 'on the meridian below the pole'. The latitude can be found easily from a lower meridian passage observation.

At lower meridian passage:

$$\text{latitude} = \text{true altitude} + (90 - \text{declination})$$

that is

$$\text{latitude} = \text{true altitude} + \text{polar distance of body.}$$

In normal navigable latitudes it is usually stars which are circumpolar as the navigator has to go to high latitudes to cause the sun or the moon to become circumpolar. He must of course be above the latitude of the arctic or antarctic circles for the sun ever

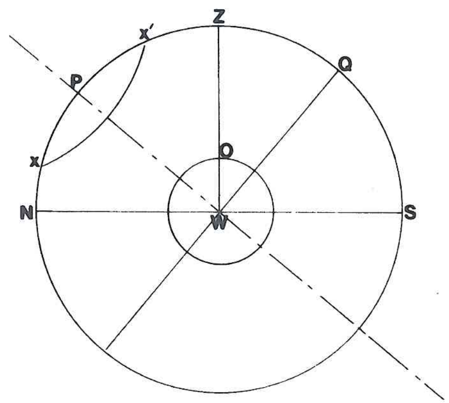

FIG. 2.6.6

to be circumpolar. In order to find the time of a stars lower meridian passage then the almanac should be consulted for the time when the stars GHA is equal to the (observer's westerly longitude + 180°). Otherwise the procedure is the same as described for finding the time of upper meridian passage.

Procedure

1. Find the LMT of lower meridian passage in order to know at what time to commence observation.
2. Extract the star's declination from the almanac.
3. Correct the altitude of the star.
4. Add the polar distance of the star to the true altitude. The latitude must be named the same as the declination.

Example

On 18th September, the sextant altitude of Atria on the meridian below the pole was 19° 41.8′. The observer's longitude was 138° 30′ E. The index error was 0.8′ on the arc and the height of eye 9.7 metres. Find the latitude and the direction of the position line.

sextant altitude	19° 41.8′	declination	69° 02.3′ S
index error	−0.8′		90°
observed altitude	19° 41.0′	polar dist.	20° 57.7′
dip	−5.5′		
apparent altitude	19° 35.5′		
total corr	−2.7′		
true altitude	19° 32.8′		
polar distance	20° 57.7′		
latitude	40° 30.5′ S		

position line runs 090/270 through 40° 30.5′ S 138° 30′ E

EXERCISE 2.6.4

1. On 18th December the sextant altitude of the star Dubhe on the meridian below the pole was 22° 19.5′. Sextant index error 2.2′ on the arc. Height of eye 12.8 metres. Find the latitude.

2. On 19th December the sextant altitude of the star Alkaid on the meridian below the pole was 12° 27.9′. Sextant index error 2.4′ on the arc. Height of eye 12.8 metres. Find the latitude.

3. On 7th January the sextant altitude of the star Schedar on the meridian below the pole was 21° 48.0′. Sextant index error 0.8′ off the arc. Height of eye 13.2 metres. Find the latitude.

4. On 20th September the sextant altitude of the star Avior on the meridian below the pole was 19° 32.4′. Sextant index error 1.2′ off the arc. Height of eye 14 metres. Find the latitude.

5. On 28th June the sextant altitude of the star Achernar on the meridian below the pole was 13° 00.4′. Sextant index error 1.4′ on the arc. Height of eye 12.5 metres. Find the latitude.

MODULE 2.7

Calculation of position lines from bodies out of the meridian

There have been many methods devised in the past of obtaining position information from astronomical observations. Most of them have been devised with the quickest possible solution in mind. Many have been in tabular form to reduce the amount of calculation required of the navigator and these have been known as short method tables or sight reduction tables. They are no doubt still in use and most navigators have found his most favoured tabular method. In professional examinations these tables have traditionally not been allowed and full solution of the PZX triangle has been taught in navigation schools. Before the ubiquitous hand held calculator a logarithmic solution was used and the haversine formula best suited this method. With the availability of calculators the importance of 'short method' tables has decreased and the haversine formula is no longer the most convenient for manual solution. Here basic principles are best demonstrated by reverting back to manual solution using the fundamental spherical cosine formula. The calculations are no longer onerous and this is probably the quickest way of producing a result. It is now accepted in professional examinations and is used here.

The navigator may want to experiment himself with his personal programmable calculator or with his computer. It is within the abilities of most competent computer owners to programme the mathematics and for this purpose the fundamental formula described is the best basis for the calculations. The Nautical Almanac gives instructions on one efficient approach to this in its explanation pages and also gives a tabular method. Commercial software is available which stores almanac data to further ease the navigator's task. Most people would agree however that complete reliance on the microchip in not desirable, certainly not without understanding the basic principles involved. It is these basic principles with which we are concerned here.

Definitions

Vertical circle. A great circle on the celestial sphere which passes through the observer's zenith.

Prime vertical. The vertical circle whose direction is east/west.

The reduction of sights of bodies out of the meridian is essentially the solution of a spherical triangle on the celestial sphere. This triangle is formed by the intersection of the three great circles, the observer's celestial meridian, the celestial meridian of the body observed and the vertical circle through the body. This triangle is represented in Figure 2.7.1.

The angles of the triangle will be:

1. Angle P. The angle at the pole between the meridians of the observer and that of the body. This is the Local Hour Angle of the body when the body is to the west of the observer's meridian and (360° – Local Hour Angle) when the body is to the east of the observer's meridian.
2. Angle Z. The angle at the zenith between the observer's meridian and the vertical circle through the body. This is the azimuth of the body.
3. Angle X. The parallactic angle. This is not used in the calculations.

The three sides of the triangle will be:

1. Side PZ. The angular distance of the zenith from the pole. This is the complement of the latitude or co-lat. (90° – latitude).
2. Side PX. The angular distance of the body from the pole. This is called the polar distance and will be equal to (90° – declination).
3. Side ZX. The angular distance of the body from the zenith. This is the zenith distance and will be equal to (90° – true altitude).

Figure 2.7.1 represents the celestial sphere drawn on the plane of the rational horizon, that is looking down from above the observer's zenith. The great circle WZE is the prime vertical and any great circle passing through Z will be a vertical circle. NS is the observer's meridian with the elevated pole in this case the north pole shown at P. The great circle WQE is the equinoctial or celestial equator. The declination circle of a body in north latitude with declination less than the latitude is shown with the body at X. Because the declination is less than the latitude the declination circle will pass closer to the equinoctial than the zenith and the body will be to the south of the observer at meridian passage. This figure is the usual projection used to illustrate the PZX triangle. As for any triangle in

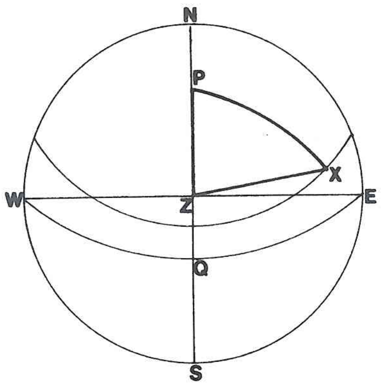

FIG. 2.7.1

order to solve we need to know, or be able to find, at least three parts either angles or sides. In fact we can only know two of its parts. PX is the complement of the declination which we can obtain from the nautical almanac as long as we have taken an accurate time of the observation. The observation of altitude when corrected will give the side ZX, the zenith distance, that is (90° − true altitude). The triangle can only be solved by making assumptions about one or more parts of the triangle, and therefore the solution will only be correct if the assumptions made are correct. The part or parts assumed will depend upon the method used.

The Intercept Method (Marcq St. Hilaire)

Module 2.5 (Position Lines and Position Circles) should have been studied and understood before reading the explanation of the calculations involved in this method.

It has been stated that any observation may be solved by this method. There are other methods which have been favoured in the past and one of these will be looked at later.

In the intercept method the arguments used are:

Side PX, the complement of the declination.
Angle P, derived by assuming a longitude which is applied to the GHA to find LHA.
Side PZ, derived by assuming a latitude and subtracting it from 90°.

The solution is made for ZX, the zenith distance and Z, the azimuth or bearing. In order to find LHA and the declination an

accurate Greenwich time of observation to the nearest second is required. This has traditionally been taken from a chronometer keeping UT, but the importance of chronometers has been reduced by the high quality of modern personal time pieces, and any good watch can be used. The important thing is that the error in the watch is regularly monitored by time signal and any error to the nearest second applied. Chronometers are normally kept on UT but if a deck watch is used the correction from the ship's time being kept by the watch to UT must also be made.

The solution gives the zenith distance and bearing which would have been observed at the time of the observation if the observer were in the assumed latitude and longitude. Remember from Module 2.5 that the zenith distance defines a position circle centred upon the geographical position of the body observed.

On the assumption that the true position is somewhere near the assumed position then the bearing calculated can be taken to be of sufficient accuracy. The calculated zenith distance however gives a position circle at right angles to the bearing passing through the assumed position. The true zenith distance derived from the observation will show whether the observer is further away from or closer to the geographical position of the body than the assumed position. The difference between the calculated and the true zenith distances is called the intercept, and named either towards or away depending on whether the true zenith distances is less than or greater than the calculated zenith distance. The true position circle will pass through the end of the intercept. (Intercept Terminal Position or ITP.) Thus one position line is defined by the direction of the position line (at right angles to the bearing), and a position through which it passes (the ITP). Two such calculations yielding two position lines will define the vessel's position.

Calculation of the zenith distance

This is best done by the use of the spherical cosine formula if a calculator is being used. This states that in the PZX triangle:

$$\text{cosine } ZX = \text{cosine } PZ \text{ cosine } PX + \text{sine } PZ \text{ sine } PX \text{ cosine } P$$

and

$$\text{cosine } Z = \frac{\text{cosine } PX - \text{cosine } PZ \text{ cosine } ZX}{\text{sine } PZ \text{ sine } ZX}$$

This can be modified by substituting complements. Thus cosine PX becomes sine declination and cosine PZ becomes sine latitude. Sine PX becomes cosine declination and sine PZ becomes cosine declination. Thus

$$\cos ZX = \sin \text{lat} \sin \text{dec} + \cos \text{lat} \cos \text{dec} \cos P$$

Care should be taken if complements are substituted. By convention P is always the elevated pole and therefore PZ will always be less than 90°, but if declination is opposite to latitude PX will be over 90° and its cosine will be negative. In this case cosine PX becomes − sine declination. The equation is therefore best remembered as

$$\cos ZX = \cos \text{lat} \cos \text{dec} \cos P + \sin \text{lat} \sin \text{dec} \text{ (lat and dec same name)}$$

$$\cos ZX = \cos \text{lat} \cos \text{dec} \cos P - \sin \text{lat} \sin \text{dec} \text{ (lat and dec opposite name)}$$

The advantage of using the formula without substituting complements is that the calculator will itself insert the correct signs and the correct answer will result without the navigator having to remember them.

The cosine formula is very easily solved with a suitable calculator. It is however unsuitable for logarithmic solution because of the multiple changes between natural and logarithmic functions. Because of this the haversine formula was developed from the cosine formula and was in general use before the availability of hand held calculators. Logarithms are rarely used now and the haversine formula naturally has fallen into disuse. It is however given here as an alternative to the cosine formula for those who still prefer to use a logarithmic solution but all examples given use the cosine formula. The versine is (1 − cosine) and the haversine is ½(1 − cosine).

Derived from the cosine formula the haversine formula states:

$$\text{haversine } ZX = (\text{haversine } P \text{ sine } PZ \text{ sine } PX) + \text{haversine } (PZ \sim PX)$$

Procedure

1. From the chronometer reading, deduce the UT. The chronometer may need 12 hours to be added to it. This can be decided by applying the longitude in time to the approximate local time to find the approximate UT. It may be that the UT is on the following or the preceding date. The date given in any problem will, as in practice, be the date at the ship.

2. With the UT extract the GHA and declination of the body observed.
3. Apply longitude to the GHA to find LHA and hence angle P in the PZX triangle. P is equal to LHA if the body is to the west of the observer and (360 − LHA) if the body is to the east of the observer.
4. Apply the cosine formula to solve for calculated zenith distance (CZX).
5. Correct the sextant altitude and obtain the true zenith distance (TZX).
6. Take the difference between CZX and TZX to be the intercept and name.
7. Calculate the bearing by ABC tables or cosine formula to give the direction of the position line.

Example 1

On 30th September at about 0900 at the ship in DR position 41° 15′ N 175° 30′ W, when a chronometer correct on UT showed 08h 25m 15s, the sextant altitude of the sun's lower limb was 28° 46.7′. Index error 0.4′ off the arc. Height of eye 15.8 metres. Find the direction of the position line and a position through which it passes.

approximate LMT	30th	09h 00m	
longitude W		11h 42m	
approximate UT	30th	20h 42m	
UT		20h 25m 15s 30th	
		(12 hours added to the chronometer)	

declination	2° 52.5′ S	sextant altitude	28° 46.7′
'd'	0.4′	index error	+0.4′
declination	2° 52.9′ S	observed alt.	28° 47.1′
		dip	−7.0′
GHA 20th	122° 30.1′	apparent alt.	28° 40.1′
increment	6° 18.8′	total corr	+14.3′
GHA	128° 48.9′	true alt.	28° 54.4′
	360°	true ZX	61° 05.6′
	488° 48.9′		
longitude	175° 30.0′ W		
LHA	313° 18.9′		
angle P	46° 41.1′		

by cosine formula

cosine ZX = cosine PZ cosine PX + sine PZ sine PX cosine P

cosine ZX = cosine 48° 45′ cosine 92° 52.9′ + sine 48° 45′ sine 92° 52.9′ cosine 46° 41.1′

= − 0.03315 + 0.51512

= 0.48197

Calculated ZX	61° 11.2′	
True ZX	61° 05.6′	
intercept		5.6′ towards

A 0.827 S		
B 0.069 S		
C 0.896 S	Azimuth	S 56.0° E or 124° T

From Figure 2.7.2 which shows a plot of the intercept and position line the ITP can be calculated if required. This is the position through which the position line passes which is asked for in the original question.

d'lat = 3.1′ S departure = 4.6′ E d'long = 4.6 sec 41° 15′ = 6.1′ E

DR Position	41° 15.0′ N		175° 30.0′ W
d'lat	3.1′ S	d'long	6.1′ E
ITP	41° 11.9′ N		175° 23.9′ W

position line runs 034°/214° through 41° 11.9′ N 175° 23.9′ W

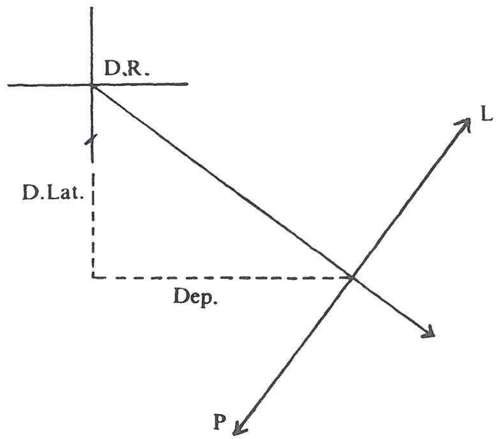

FIG. 2.7.2

Notes:

1. Intermediate steps have been shown in solving the cosine formula equations. These can be dispensed with by a navigator who is proficient with his calculator.

2. The cosine formula to solve for zenith distance may be manipulated by using complements. Thus:

cosine ZX = cosine PZ cosine PX + sine PZ sine PX cosine P

is equivalent to:

cos ZX = cos lat cos dec cos P + sin lat sin dec

(if declination is opposite name to latitude then PX is over 90 and cosine PX = − sine dec. It must be remembered that a negative sign is applied to sine dec in this case).

cos ZX = cos 41° 15′ cos 2° 52.9′ cos 46° 41.1′ − sin 41° 15′ sin 2° 52.9′

cos ZX = 0.51512 − 0.03317

ZX = 61° 11.2′

3. The azimuth in the above example was found by using ABC tables. It could equally well be calculated by the cosine formula which states:

$$\text{cosine Z} = \frac{\text{cosine PX} - \text{cosine PZ cosine ZX}}{\text{sine PZ sine ZX}}$$

or

$$\text{cosine Z} = \frac{\text{cosine } 92°\ 52.9' - \text{cosine } 48°\ 45' \text{ cosine } 61°\ 05.6'}{\text{sine } 48°\ 45' \text{ sine } 61°\ 05.6'}$$

= −0.56068

= N 124.1° E or 124° T

EXERCISE 2.7.1

1. On 27th June at about 0900 at the ship in DR position 29° 30′ S 121° 20′ W, when a chronometer which was correct on UT showed 05h 05m 20s. The sextant altitude of the sun's lower limb was observed to be 21° 11.9′. Sextant index error 1.6′ on the

arc. Height of eye 12.0 metres. Find the direction of the position line and a position through which it passes.

2. On 8th January at about 1510 at the ship in DR position 32° 15′ S 48° 16′ W, when a chronometer which was correct on UT showed 06h 21m 24s. The sextant altitude of the sun's upper limb was observed to be 48° 59.9′. Sextant index error 0.4′ on the arc. Height of eye 11.0 metres. Find the direction of the position line and a position through which it passes.

3. On 19th September at about 1547 at the ship in DR position 00° 00′ 160° 55′ W, when a chronometer which was correct on UT showed 02h 29m 15s. The sextant altitude of the sun's lower limb was observed to be 31° 46.9′. Sextant index error 0.6′ off the arc. Height of eye 12.5 metres. Find the direction of the position line and a position through which it passes.

4. On 18th December at about 0846 at the ship in DR position 43° 12′ N 38° 25′ W, when a chronometer which was 02m 21s fast on UT showed 11h 21m 52s. The sextant altitude of the sun's lower limb was observed to be 10° 23.9′. Sextant index error 1.6′ off the arc. Height of eye 11.5 metres. Find the direction of the position line and a position through which it passes.

5. On 30th September at the ship in DR position 44° 05′ N 27° 41′ W, at UT 09h 26m 02s. The sextant altitude of the sun's lower limb was observed to be 16° 26.8′. Sextant index error 1.4′ on the arc. Height of eye 9.0 metres. Find the direction of the position line and a position through which it passes.

Example 2

On 9th January at approximate ship's time 1940 in assumed position of 35° 10′ S 127° 50′ E the sextant altitude of the star Sirius was observed to be 37° 07.3′. Sextant index error 0.4′ on the arc. Height of eye 15 metres. A chronometer which was correct on UT showed 11h 15m 10s. Find the direction of the position line and a position through which it passes.

approximate LMT	9th	19h 40m
longitude W		08h 31m
approximate UT	9th	11h 09m
UT		11h 15m 10s 9th

declination	16° 43.2′ S
GHA♈ 11h	273° 34.2′
increment	3° 48.1′
GHA ♈	277° 22.3′
SHA Sirius	258° 40.7′
GHA Sirius	536° 03.0′
	360°
GHA Sirius	176° 03.0′
longitude	127° 50.0′ E
LHA Sirius	303° 53.0′
angle P	56° 07.0′

sextant altitude	37° 07.3′
index error	−0.4′
observed alt.	37° 06.9′
dip	−6.8′
apparent alt.	37° 00.1′
total corr	−1.3′
true alt.	36° 58.8′
true ZX	53° 01.2′

by cosine formula

cosine ZX = cosine PZ cosine PX + sine PZ sine PX cosine P

cosine ZX = cosine 54° 50′ cosine 73° 16.8′ + sine 54° 50′ sine 73° 16.8′ cosine 56° 07′

= 0.16570 + 0.43648

ZX = 52° 58.4′

or

cos ZX = cos lat cos dec cos P + sin lat sin dec

cos ZX = cos 35° 10′ cos 16° 43.2′ cos 56° 07′ + sin 35° 10′ sin 16° 43.2′

cos ZX = 0.43648 + 0.16570

ZX = 52° 58.4′

Calculated ZX	52° 58.4′	A 0.473 N	
True ZX	53° 01.2′	B 0.362 S	
intercept	2.8′ away	C 0.111 N	Azimuth N 84.8° E or 085° T

From Figure 2.7.3 d'lat = 0.3′ S

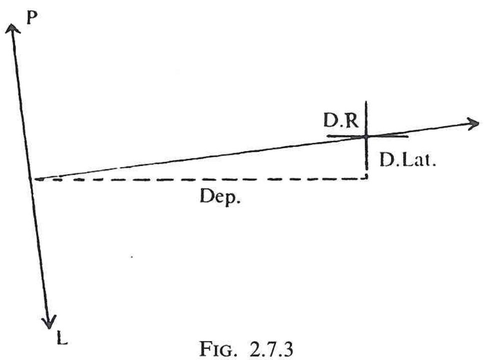

FIG. 2.7.3

departure = 2.8′ W d’long = 2.8 sec 35° 10′ = 3.4′ W

DR position	35° 10.0′ S		127° 50.0′ E
d’lat	0.3′ S	d’long	3.4′ W
ITP	35° 10.3′ S		127° 46.6′ E

position line runs 355°/175° through 35° 10.3′ N 127° 46.6′ E

EXERCISE 2.7.2

1. On 19th September at approximate ship’s time 1800 in DR position 24° 30′ N 145° 10′ E, at UT 08h 19m 50s. The sextant altitude of the star Arcturus was observed to be 40° 07.7′. Sextant index error 0.8′ on the arc. Height of eye 12.0 metres. Find the direction of the position line and a position through which it passes.

2. On 30th September at approximate ship’s time 0600 ship in DR position 43° 05′ N 177° 16′ W, at UT 17h 01m 44s. The sextant altitude of the star Schedar was observed to be 41° 54.4′. Sextant index error 0.2′ off the arc. Height of eye 13.2 metres. Find the direction of the position line and a position through which it passes.

3. On 19th September at the ship in assumed position 17° 53.6′ N 47° 30.0′ W, when the chronometer, which was 04m 53s slow on UT, showed 08h 10m 23s. The sextant altitude of the star Alphard during morning twilight was observed to be 18° 06.5′. Sextant index error 0.5′ on the arc. Height of eye 18.6 metres. Find the direction of the position line and a position through which it passes.

4. On 18th December at approximately 0600 at the ship in DR position 42° 40′ N 172° 10′ W, at UT 17h 29m 30s the sextant altitude of the star Alphecca was observed to be 41° 46.7′. Sextant index error 1.3′ on the arc. Height of eye 17.5 metres. Find the direction of the position line and a position through which it passes.

5. On 27th June at the ship at evening stars in DR position 40° 59.5′ S 56° 57′ W, at UT 21h 26m 00s. The sextant altitude of the star Procyon was observed to be 15° 03.1′. Sextant index error 0.6′ off the arc. Height of eye 9.0 metres. Find the direction of the position line and a position through which it passes.

Example 3
On 30th September at approximate ship’s time 1319 in assumed position of 14° 38′ S 54° 14′ W the sextant altitude of the moon’s lower limb was observed to be 44° 37.4′. Sextant index error nil. height of eye 12 metres. A chronometer which was correct on UT showed 04h 25m 14s. Find the direction of the position line and a position through which it passes.

approximate LMT	30th 13h 19m	chron.	04h 25m 14s
longitude W	03h 37m	UT	16h 25m 14s 30th
approximate UT	30th 16h 56m		

declination	23° 22.5′ S	sextant altitude	44° 37.4′
‘d’	+3.7′	index error	–
declination	23° 26.2′ S	observed alt.	44° 37.4′
		dip	−6.1′
GHA 16th	1° 53.1′	apparent alt.	44° 31.3′
increment	6° 01.3′	main corr	+50.8′
‘v’	2.3′	2nd corr	+7.1′
GHA	7° 56.7′	true altitude	45° 29.2′
longitude	54° 14.0′ W	zenith dist.	44° 30.8′
LHA	313° 42.7′		
angle P	46° 17.3′		

by cosine formula

cosine ZX = cosine PZ cosine PX + sine PZ sine PX cosine P
cosine ZX = cosine 75° 22′ cosine 66° 33.8′ + sine 75° 22′ sine 66° 33.8′ cosine 46° 17.3′
= 0.10048 + 0.61345
ZX = 44° 26.6′

or

cos ZX = cos lat cos dec cos P + sin lat sin dec
cos ZX = cos 14° 38′ cos 23° 26.2′ cos 46° 17.3′ + sin 14° 38′ sin 23° 26.2′
cos ZX = 0.61345 + 0.10048
ZX = 44° 26.6′

Calculated ZX	44° 26.6′
True ZX	44° 30.8′
intercept	4.2′ away

A 0.250 N
B 0.600 S
C 0.350 S   Azimuth   S 71.3° E or 108.7° T

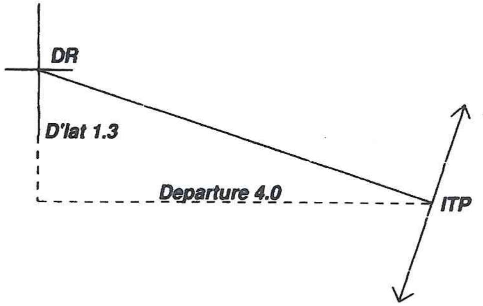

FIG. 2.7.4

From Figure 2.7.4

d'lat = 1.3′ N departure = 4.0′ W d'long = 4.0 sec 14° 38′ = 4.1′ W

DR position	14° 38.0′ S		54° 14.0′ W
d'lat	1.3′ N	d'long	4.1′ W
ITP	14° 36.7′ S		54° 18.1′ W

position line runs 018.7°/198.7° through 14° 36.7′ S 54° 18.1′ W

EXERCISE 2.7.3

1. On 28th June at approximately 0620 at a ship in assumed position 42° 50′ N 41° 30′ W the sextant altitude of the moon's lower limb was 31° 51.8′. A chronometer which was correct on UT showed 09h 10m 02s. Index error 2.0′ off the arc. Height of eye 10 metres. Find the direction of the position line and a position through which it passes.

2. On 9th January at approximately 1550 hrs at a ship in assumed position 25° 30′ N 175° 00′ E the sextant altitude of the moon's upper limb was 55° 29.4′. A chronometer which was slow on UT by 1m 24s showed 04h 06m 41s. Index error 2.0′ on the arc. Height of eye 7.2 metres. Find the direction of the position line and a position through which it passes.

Longitude by chronometer
In this method a latitude is assumed. This is used in the PZX triangle with declination and the true zenith distance to solve for angle P and hence Local Hour Angle and longitude. This longitude

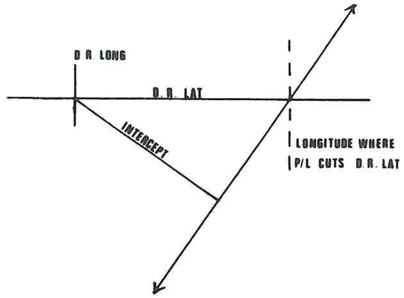

FIG. 2.7.5

will be correct only if the assumed latitude was correct and thus the assumed latitude and calculated longitude give a position through which the position line passes. The direction of the position line must be found as before.

For any one observation there obviously is only one position line regardless of the method used to reduce the observation. The intercept method and the longitude method however result in different positions through which the position line is drawn. Figure 2.7.5 shows the relationship between the information gained from the two methods.

The arguments used to solve the PZX triangle in the longitude by chronometer method are:

1. PZ. This is the complement of the latitude.
2. PX. This is the complement of the declination.
3. ZX. This is the zenith distance or complement of the true altitude.

By cosine formula:

$$\text{cosine P} = \frac{\text{cosine ZX} - \text{cosine PZ cosine PX}}{\text{sine PZ sine PX}}$$

or

$$\text{cosine P} = \frac{\text{cosine ZX} - \sin \text{lat} \sin \text{dec}}{\cos \text{lat} \cos \text{dec}} \quad \text{(lat and dec same name)}$$

$$\text{cosine P} = \frac{\text{cosine ZX} + \sin \text{lat} \sin \text{dec}}{\cos \text{lat} \cos \text{dec}} \quad \text{(lat and dec opposite names)}$$

If complements are substituted it must be remembered that sine declination must carry a negative sign if the latitude and declination are of opposite names.

Procedure

1. From the chronometer time deduce the UT and the date at Greenwich.
2. Using the UT extract the GHA and the declination from the almanac.
3. Correct the sextant altitude and obtain the zenith distance.
4. Solve the cosine formula for angle P and hence the LHA.
5. Apply GHA to LHA to obtain the longitude.
6. Find the true bearing and the direction of the position line.

This method is not suitable for bodies which are close to the meridian. As a rule of thumb it may be said that the body should be at least two hours from its meridian passage. It is particularly suitable for observations of the sun in the forenoon which are going to be run up to noon and combined with a latitude by meridian altitude.

Example 4

On 30th September at about 0900 at the ship in DR position 41° 15′ N 175° 30′ W, when a chronometer correct on UT showed 08h 25m 15s, the sextant altitude of the sun's lower limb was 28° 46.7′. Index error 0.4′ off the arc. Height of eye 15.8 metres. Find the direction of the position line and a position through which it passes.

approximate LMT	30th 09h 00m
longitude W	11h 42m
approximate UT	30th 20h 42m
UT	20h 25m 15s 30th

GHA 20h	122° 30.1′	sextant altitude	28° 46.7′
increment	6° 18.8′	index error	+0.4′
GHA	128° 48.9′	observed alt.	28° 47.1′
		dip	−7.0′
declination	2° 52.5′ S	apparent alt.	28° 40.1′
'd' corr	+0.4′	total corr	+14.3′
declination	2° 52.9′ S	true altitude	28° 54.4′
		zenith dist.	61° 05.6′

$$\text{cosine P} = \frac{\text{cosine ZX} - \text{cosine PZ cosine PX}}{\text{sine PZ sine PX}}$$

or

$$\text{cosine P} = \frac{\text{cosine ZX} + \sin \text{lat} \sin \text{dec}}{\cos \text{lat} \cos \text{dec}}$$

$$\text{cosine P} = \frac{\text{cosine } 61^\circ\ 05.6' + \sin 41^\circ\ 15' \sin 2^\circ\ 52.9'}{\cos 41^\circ\ 15' \cos 2^\circ\ 52.9'}$$

$$= \frac{0.48338 + 0.03315}{0.75089}$$

P =	46° 32.2′	A 0.831S
LHA	313° 27.8′	B 0.069 S
GHA	128° 48.9′	C 0.900 S
longitude	175° 21.1′	Azimuth S 55.9° E or 124.1° T

Position line runs 034.1°/214.1° through 41° 15′ N 175° 21.1′ W

EXERCISE 2.7.4

1. On 28th June at approximately 1600 at the ship in DR position 10° 25′ N 71° 00′ E, when the chronometer, which was fast on UT by 4m 27s, showed 1 1 h 19m 53s, the sextant altitude of the sun's lower limb was 31° 33.3′. Index error 1.2′ on the arc. Height of eye 17.0 metres. Find the direction of the position line and the longitude in which it cuts the parallel of the DR latitude.

2. On 19th September at approximately 0730 at the ship in DR position 18° 44′ N 127° 00′ W when the chronometer, which was correct on UT, showed 04h 01m 42s, the sextant altitude of the sun's upper limb was 24° 34.5′. Index error 0.6′ off the arc. Height of eye 18.0 metres. Find the direction of the position line and the longitude in which it cuts the parallel of the DR latitude.

3. On 20th December during the forenoon at the ship in DR position 35° 24′ S 171° 15′ E, when the chronometer, which was slow on UT by 1m 17s, showed 09h 00m 35s, the sextant altitude of the sun's lower limb was 43° 09.7′. Index error 0.4′ on the arc. Height of eye 14.5 metres. Find the direction of the position line and the longitude in which it cuts the parallel of the DR latitude.

4. On 4th January during the forenoon at the ship in DR position 0° 30′ S, 0° 04′ E when the chronometer, which was correct

on UT, showed 08h 15m 35s, the sextant altitude of the sun's upper limb was 30° 27.1′. Index error 1.4′ on the arc. Height of eye 19.5 metres. Find the direction of the position line and the longitude in which it cuts the parallel of the DR latitude.

5. On 30th September at approximately 0800 at the ship in DR position 44° 05′ N 20° 05′ W at UT 09h 11m 02s, the sextant altitude of the sun's lower limb was 18° 57.5′. Index error 1.4′ on the arc. Height of eye 9.0 metres. Find the direction of the position line and the longitude in which it cuts the parallel of the DR latitude.

Noon position by longitude by chronometer and meridian altitude

A standard method of obtaining a noon position when there is only the sun available for observation is to observe the sun when it is bearing close to east in the forenoon and transfer the position line calculated by longitude by chronometer to the time of noon, that is meridian passage of the sun. The transferred position line can then be crossed with a position line obtained from a latitude by meridian altitude. The noon position can be found without any plotting.

Figure 2.7.6 represents such a morning position line which has been run up to give a noon DR position. The transferred position through this DR is shown with double arrows. The figure shows that if the noon latitude gives a latitude to the south of the DR then the ship's position must be to the west. If the noon latitude

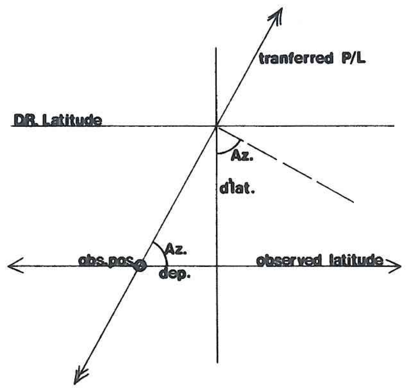

FIG. 2.7.6

is to the north of the DR then the position must be to the east. The amount by which the longitude differs from the DR longitude is given by the number of minutes the noon latitude differs from the DR latitude multiplied by the value 'C' which will have been obtained when working the azimuth at the forenoon sight.

Thus the value 'C' in this respect can be taken as the error in the longitude caused by an error of 1 minute in the latitude.

Example 5

On 19th December at approximate ship's time 0810 in assumed position 25° 50′ N 50° 00′ W an observation of the sun's lower limb gave a sextant altitude of 15° 47.5′. Index error was 3.0′ on the arc and height of eye 13.6 metres. The chronometer showed 11h 26m 04s at the time and was slow on UT by 1m 03s. The ship then steamed 210° T for 55 miles, when a meridian altitude of the sun's lower limb was 41° 19.8′ south of the observer. Find the ship's position at noon.

Approximate ship's time	0810	
longitude in time	0349	
approximate UT	1159	19th

chronometer	11h 26m 04s		sextant altitude	15° 47.5′
error	1m 03s		index error	−3. 0′
UT	11h 27m 07s	19th	observed alt.	15° 44.5′
			dip	−6.5′
GHA 11h	345° 46.7′		apparent alt.	15° 38.0′
increment	6° 46.8′		total corr	+12.9′
GHA	352° 33.5′		true altitude	15° 50.9′
			zenith dist.	74° 09.1′

declination 23° 24.5′ S

$$\text{cosine P} = \frac{\text{cosine ZX} - \sin \text{lat} \sin \text{dec}}{\cos \text{lat} \cos \text{dec}}$$

$$\text{cosine P} = \frac{\text{cosine } 74°\ 09.1' + \sin 25°\ 50' \sin 23°\ 24.5'}{\cos 25°\ 50' \cos 23°\ 24.5'}$$

$$= \frac{0.27309 + 0.17312}{0.82599}$$

P=	57° 18.1′	A 0.311 S	
LHA	302° 41.9′	B 0.515 S	
GHA	352° 33.5′	C 0.826 S	azimuth S 53.2° E
longitude	49° 51.6′		pos line runs 036.8°/216.8°

DR at forenoon sight	25° 50.0′ N	49° 51.6′ W
run 210° T × 55 miles	47.6′ S	30.5′ W
noon DR	25° 02.4′ N	50° 22.1′ W

meridian altitude

mer. pass.	1157	sextant altitude	41° 19.8′
longitude	0322	index error	−3.0′
UT mer. pass.	1519	observed alt.	41° 16.8′
		dip	−6.5′
declination	23° 24.8′	apparent alt.	41° 10.3′
		total corr	+15.2′
		true altitude	41° 25.5′
		zenith dist.	48° 34.5′
		declination	23° 24.8′ S
		latitude	25° 09.7′ N
		DR lat.	25° 02.4′ N
		difference	7.3′ N
		'C'	0.826
		long error	6.0′ E

noon DR long	50° 22.1′ W
long correction	6.0′ E
noon longitude	50° 16.1′ W

noon position	25° 09.7′ N	50° 16.1′ W

EXERCISE 2.7.5

1. On 30th September during the forenoon in assumed position 46° 17′ S 157° 20′ W an observation of the sun's lower limb gave a sextant altitude of 32° 15′. Index error was 3.0′ off the arc and height of eye 11 metres. The chronometer showed 07h 24m 51s at the time and was correct on UT. The ship then steamed 300° T for 45 miles, when a meridian altitude of the sun's lower limb was 46° 47.9′ north of the observer. Find the ship's position at noon.

2. On 28th June during at approximate ship's time 0919 in assumed position 38° 15′ S 168° 15′ E an observation of the sun's lower limb gave a sextant altitude of 17° 18.2′. Index error was 1.0′ on the arc and height of eye 8.0 metres. The chronometer showed 10h 05m 17s at the time and was correct on UT. The ship then steamed 045° T for 40 miles, when a meridian altitude of the sun's lower limb was 28° 39.4′ north of the observer. Find the ship's position at noon.

MODULE 2.8

Latitude by Pole Star

The altitude of the celestial pole is equal to the observer's latitude. Unfortunately the exact position of the pole is not marked and cannot be observed. However the star Polaris has a declination in excess of 89°, so that it describes daily a circle around the pole of radius less than one degree. As it is so near the pole it is referred to as the pole star and its altitude can be observed and small adjustments made to the altitude to give an easy derivation of the latitude.

Figure 2.8.1 represents the daily path of Polaris around the pole. Its polar distance has been exaggerated. If the star is at X_1 the angular distance PX_1, the polar distance, must be subtracted from the altitude NX_1 to obtain the altitude of the pole, or the latitude. Similarly if the star is at X_2 then the polar distance must be added to the altitude of the star to give that of the pole. At all other times the correction will be the arc PY in Figure 2.8.1 and this may be

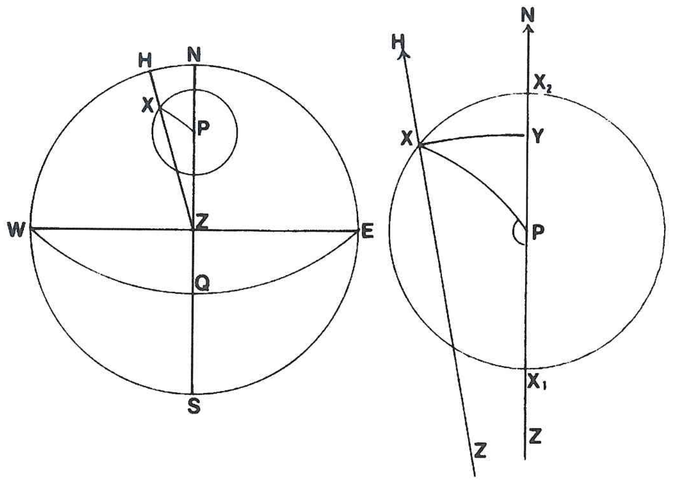

Fig. 2.8.1

positive as shown or negative. The solution of the triangle XPY for PY is tabulated in the Nautical Almanac under the title 'Pole Star Tables'. These are found in the back of the almanac.

The solution is arranged in three separate quantities a^0, a^1 and a^2. To each is added a constant, and the sum of the three constants is 1°, which must be subtracted at the end of the calculation. This is done to ensure that all corrections are always positive.

The correction depends upon the LHA of the star. As the SHA can be considered constant for the year it is preferable to tabulate against the argument LHA ♈.

Procedure

1. From the UT of observation find the GHA ♈ and apply the DR longitude to get LHA ♈.
2. Correct the sextant altitude to obtain true altitude.
3. Using LHA ♈, enter the pole star tables and find the column which is headed by the value of LHA ♈. There is one column for each 10 degrees of LHA. The three corrections will be found in the same vertical column, which is divided into three sections.

The top section is tabulated against each degree of LHA within the 10° range and a^0 can be extracted with some simple interpolation if necessary.

The middle section is tabulated against latitude and a^1 can be read against the latitude and no interpolation is necessary.

The lower section is tabulated against the month and a^2 can be read off against the correct month without interpolation.

4. The altitude of the pole is given by (true altitude of Polaris $+a^0 + a^1 + a^2 - 1$).
5. Read off the bearing of the star against the latitude from the azimuth table at the foot of the column.

Note: The pole star will not always bear due north and therefore the position line will not be exactly along a parallel. The bearing however will be so close to north that it is usually assumed that the position line does coincide with the observer's parallel. Strictly speaking the latitude derived together with the DR longitude used give a position through which the position line passes with a direction which may be up to 1.7 degrees from east/west.

Example

On 21st September in DR position 37° 58′ N 52° 30′ E at 01h 10m 24s UT an observation of Polaris gave sextant altitude 38° 40.4′. Index error 2.2′ off the arc. Height of eye 11.7m. Find the direction of the position line and a position through which it passes.

UT. 01h 10m 24s 21st

GHA♈ 01h	14° 30.0′	sextant altitude	38° 40.4′
increment	2° 36.4′	index error	+2.2′
GHA ♈	17° 06.4′	observed alt.	38° 42.6′
longitude E	52° 30.0′	dip	−6.0′
LHA ♈	69° 36.4′	apparent alt.	38° 36.6′
		total corr	−1.2′
		true altitude	38° 35.4′
		a^0	0° 21.7′
		a^1	0.6′
		a^2	0.3′
		total	38° 58.0′
			1°
		latitude	37° 58.0′ N
		bearing	359.6° T

position line runs 269.6°/089.6° through 37° 58.0′ N 52° 30′ E

EXERCISE 2.8.1

1. On 8th January at 19h 25m 22s UT in DR position 49° 20′ N 36° 20.4′ W the sextant altitude of Polaris was 50° 09.4′. The sextant index error was 1.6′ off the arc and the height of eye 12.8 metres. Find the direction of the position line and a position through which it passes.

2. On 20th September at 21h 15m 40s UT in DR position 35° 25′ N 36° 25′ W the sextant altitude of Polaris was 35° 15.8′. The sextant index error was 0.8′ on the arc and the height of eye 11.5 metres. Find the direction of the position line and a position through which it passes.

3. On 27th June at 13h 26m 44s UT in DR position 47° 15′ N 158° 40′ W the sextant altitude of Polaris was 47° 42.0′. The sextant index error was 1.4′ off the arc and the height of eye 6.0 metres. Find the direction of the position line and a position through which it passes.

4. On 30th September at about 0520 local time in DR position 50° 40′ N 162° 10.8′ E the sextant altitude of Polaris was 51° 10.8′. The chronometer which was 02m 08s slow on UT showed 06h 13m 17s. The sextant index error was 1.2′ off the arc and the height of eye 14.0 metres. Find the direction of the position line and a position through which it passes.

REVISION EXERCISES

Paper 1

Chart: Lands End to Falmouth **Use variation 5° W throughout**

Use the deviation card in Figure Module 1.3

1. At a time 5 hours after high water Dover on spring tides a vessel was in a position with Lizard Lt. bearing 000° T distant 5 miles. Find the compass course to steer to pass 3 miles to the south of Wolf Rock Light, making allowance for any tide you may expect. Estimate the sailing time to the position off Wolf Rock. Vessel's log speed is 12 knots.

2. From a vessel to the south of Mount's Bay steering 091° C speed 8 knots Black Head was observed in transit with Lizard lighthouse bearing 051° C. After maintaining this course for one hour Lizard lt. hse. bore 309° C. If a current set 070° T at 1.5 knots in the interval find the position of the ship at the time of the second observation.

3. It is required to round Lizard point maintaining a distance off Men Hyr Rocks of 1.5 miles. What would be the vertical sextant angle to set on a sextant to observe Lizard light hse.?

4. A vessel steering 110° C speed 10 knots observed Longships Lt. bearing 345° C and Tater Du Lt. hse. bearing 035° C. 1.5 hours later Lizard Point lt. hse. was bearing 065° C while Mullion Island was bearing 029° C. Find the set and the drift of the tide in the interval.

5. Find by plane sailing the vessel's position at the end of the third course.

Initial position	49° 30′ N	8° 00′ W
1st course	261° T	distance 70 miles
2nd course	210° T	distance 72 miles
3rd course	166° T	distance 65 miles

6. Find by plane sailing the course and distance between the following positions.

50° 15′ N	5° 25′ W
52° 10′ N	7° 05′ W

7. From the following information find the compass error and the deviation for the ship's head.

Date June 27th	DR position 50° 30′ N 6° 30′ W
sun rose bearing 053°C	Variation 8° W

Paper 2

Chart: Falmouth to Plymouth **Use 5° W variation throughout**

Use the deviation card in Module 1.3

1. From a position where Eddystone Rock Lt. bears 000° T distant 3 miles find the compass course to steer to a position where Dodman Point bears 307° T distant 2.4 miles, in order to counteract a tide estimated to set 133° T at 2 knots and allowing for a 10° leeway due to a SW'ly wind. Ships speed by log 8 knots.

2. The following compass bearings were obtained from a vessel at anchor in Mevagissey Bay:

Chapel Point	238° C
Black Head	001° C
Gribbin Head daymark	056° C

Find the latitude and longitude of the vessel's position and the compass course to steer to arrive at a position where Rame Head chapel ruins is bearing 000° T by 3 miles.

3. A vessel steering 330° C has the buoy (FL R 10 sec) (50° 07′ N 4° 30′ W approximately) bearing 015° C distant 1.2 miles. After steaming for 40 minutes at 12 knots the vessel's position was fixed by three bearings:

Gribbin Head	003° C
Chapel Point	320° C

Find the set and rate of the current, the course and speed made good.

4. Find the rising and dipping distance of Eddystone Light from a vessel with height of eye 12.5 metres.

5. Find by mercator sailing the position at the end of the run.

Initial position	55° 55′ N	7° 18′ E
Course	257° C	Variation 8° W Deviation 3° E
Distance run	120 miles	

6. From the following information find the compass error and the deviation for the ship's head.

Time at ship 1608 29th September. DR position 43° 30′ N 9° 40′ W
Bearing of the sun by compass 262°. Chronometer 05h 08m 02s.
Chronometer error 2m 18s slow on UT. Variation 6° W.

Paper 3

Chart: Lands End to Falmouth **Use variation 6° W throughout**

Use the deviation card in Module 3

1. At 0800 hrs in poor visibility, from a vessel steering 181° by gyro, speed 5 knots, the Longships lighthouse bore 148° G. Gyro error 1° High. The vessel continued on this course and at 0915 Wolf Rock Lt. was observed to bear 238° G. If a tide set 127° T at 2 knots throughout find the vessels position at 0915.

2. From a position with Wolf Rock Lt. bearing 350° T distance 2.4 miles, find the course and distance to a position 49° 46′ N 5° 26.6′ W. Find also the compass course to steer to counteract a tide setting 084° T at 3 knots and 6 degrees leeway due to a SW'ly wind, if the vessel's speed by log is 6 knots. What will be the steaming time to the position given.

3. On a vessel at anchor off Falmouth the following compass bearings were taken:

Manacle Point	226° C
Rosemullion Head	280° C
St Anthony Head Lt.	010° C

Find the vessel's position and the error of the compass.

4. At 1000 hrs, the Runnel Stone buoy was observed in transit with Longships lighthouse bearing 318° C. At the same time Wolf Rock bore 251° C. Find the vessel's position. If the course is now set 095° C and 20 minutes later Tater Du Lt. bore 321° C and St Michael's Mount bore 014° C, estimate the set and the drift of the tide if the distance run by log in the interval was 5 miles.

5. Find the times and heights of high and low waters at Sharpness Dock on 14th January.

Paper 4

1. From the following information find the direction of the position line and a position through which it passes:

Time at ship 0825 20th September
DR position 5° 58′ S 126° 03′ E
Sextant altitude Saturn 50° 39.2′
Index error 1.5′ off the arc
Ht of eye 14.5 metres
Chronometer 00h 27m 38s (correct on UT)

2. Find the GMT and LMT of meridian passage of the star Vega and the setting to put on a sextant to observe this passage:

Date at ship 19th September
DR position 13° 00′ S 138° 55′ E
Index error 1.8′ Off the arc
Height of eye 17.0 metres

3. Find by Mercator sailing the course and distance from 48° 11′ S 169° 50′ E to 23° 36′ S 161° 42′ W.

4. From the following information find the compass error and the deviation for the ship's head:

Time at ship 1004 18th December
DR position 55° 08′ N 5° 13′ E
Sun bore 162° by compass
Chronometer 10h 02m 17s
Chronometer error 1m 40s fast on UT
Variation 7° W

Paper 5

1. From the following information find the direction of the position line and a position through which it passes:

Time at ship 1930 28th June
DR position 33° 05′ N 131° 18′ W
Sextant altitude Regulus 34° 54.4′
Index error 1.0′ on the arc
Ht of eye 16.7 metres
Chronometer 04h 12m 13s
Chronometer error 1m 03s fast on UT

2. From the following information find the direction of the position line and a position through which it passes:

Time at ship 1210 7th January
DR position 26° 17′ N 48° 11′ W
Sextant altitude Sun LL 41° 16.9′
Index error 2.0′ on the arc
Ht of eye 13.2 metres

Chronometer 03h 18m 06s
Chronometer error 7m 14s fast on UT

3. From the following observation of Polaris during evening twilight find the direction of the position line and a position through which it passes:

Date at ship 27th June
DR position 21° 03′ N 153° 16′ W
Sextant altitude 20° 15′
Index error 2.0′ on the arc
Height of eye 11.5 metres
Chronometer 05h 27m 42s
Chronometer error 1m 29s slow on UT

4. From the following sights find the position of the ship at the time of the second observation:

Assumed position 40° 12′ S 94° 30′ E
Observed longitude 94° 33′ E
Bearing 079° T
Run 3.5 hours at 16 knots
Course 352° T
Current 260° T 2 knots
Using assumed position run up intercept 3.0′ Towards bearing 012° T

Paper 6

1. From the following information find the direction of the position line and a position through which it passes:

Time at ship 1429 29th September
DR position 47° 30′ N 45° 20′ W
Sextant altitude Sun LL 29° 14.3′
Index error 2.0′ on the arc
Ht of eye 6.2 metres
Chronometer 05h 29m 13s
Chronometer error 1m 03s fast on UT

2. From the following meridian observation find the latitude and state the direction of the position line:

Date at ship 9th January
DR position 51° 28′ S 136° 30′ E
Sextant altitude Moon's LL 40° 15.7′
Index error nil
Height of eye 16.3 metres

3. Find by Mercator sailing the arrival position:

Initial position 46° 45′ N 45° 00′ W
Course 337° T distance 245 miles

4. From the following information find the error of the compass and the deviation for the ship's head:

Date at ship 29th September
DR position 10° 50′ N 157° 17′ W
Sun bore 273° by compass when setting
Variation 4° E

Paper 7

1. From the following information find the direction of the position line and a position through which it passes:

Time at ship 1407 9th January
DR position 12° 10′ N 50° 05′ W
Sextant altitude Moon UL 37° 46.1′
Index error 1.0′ on the arc
Ht of eye 6.2 metres
Chronometer 17h 25m 01s
Chronometer error 0m 48s slow on UT

2. From the following information find the direction of the position line and a position through which it passes:

Time at ship 0508 20th September
DR position 38° 40′ S 138° 46′ E
Sextant altitude Bellatrix 44° 50.0′
Index error 3.0′ off the arc
Ht of eye 9.9 metres
Chronometer 08h 12m 19s
Chronometer error 2m 18s fast on UT

3. From the following meridian observation find the latitude and state the direction of the position line:

Date at ship 20th September
DR position 26° 00′ N 116° 30′ W
Sextant altitude Sun LL 64° 45.0′
Index error 1.5′ on the arc
Height of eye 17.9 metres

4. From the following sights find the position of the ship at the time of the second observation:

Time 1300
Assumed position 23° 57′ N 92° 07′ W
Intercept 3.0′ Towards Brg 287° T
Run 95 miles
Course 147° T
Time 1830
Using assumed position run up intercept 5.0 Away bearing 030° T

Paper 8

1. From the following information find the direction of the position line and the longitude in which it cuts the DR latitude:

Time at ship 0840 29th September
DR position 30° 40′ N 175° 18′ E
Sextant altitude Sun LL 34° 35.0′
Index error 1.0′ off the arc
Ht of eye 10.3 metres
Chronometer 09h 01m 13s
Chronometer error nil

2. From the following meridian observation find the latitude and state the direction of the position line:

Date at ship 6th January
DR longitude 96° 35′ E
Sextant altitude Sun UL bearing south 41° 25.0′
Index error 2.0′ on the arc
Height of eye 11.5 metres

3. From the following observation of Polaris during morning twilight find the direction of the position line and a position through which it passes:

Date at ship 27th June
DR position 47° 15′ N 125° 40′ W
Sextant altitude 47° 52′
Index error 0.5′ off the arc
Height of eye 6.1 metres
Chronometer 11h 01m 44s
Chronometer error nil

4. From the following sights worked using the DR position given, find the ship's position at 1746:

Course 071° T speed 20 knots
DR position 42° 11′ S 161° 17′ E

Time 1731	Intercept 5.8′ Towards bearing 026° T
Time 1737	Intercept 2.9′ Away bearing 272° T
Time 1746	Intercept 1.7′ Towards bearing 319° T

ANSWERS TO EXERCISES

Exercise 1.1.1

1. 425′ N	709′ W	2. 910′ N	635′ E
3. 930′ S	741′ W	4. 2026′ N	522′ E
5. 741′ N	1278′ W	6. 1005′ S	300′ E
7. 995′ N	3712′ W	8. 2910′ N	4425′ E
9. 1508′ N	8226′ W	10. 2983′ N	3516′ E

Exercise 1.1.2

1. 12° 24.0′ N	165° 34.0′ W	2. 43° 37.0′ N	17° 46.0′ E
3. 42° 08.2′ N	34° 14.4′ W	4. 17° 45.1′ S	170° 59.5′ E

Exercise 1.3.1

1. 1° E	2. 14° E	3. 5° E	4. 1° W	5. 17° W
6. 12° E	7. 2° W	8. 1° W		

Exercise 1.3.2

1. 217.5° T	2. 004° T	3. 004° T	4. 264.5° T	5. 042.5° T
6. 333° T	7. 353° T	8. 093.5° T		

Exercise 1.3.3

1. 240° C	2. 008° C	3. 355.5° C	4. 260° C	5. 033.5° C
6. 325.5° C	7. 079° C	8. 246.5° C		

Exercise 1.3.4

1. 351.5° T	2. 347.5° T	3. 160.5° T	4. 253° T	5. 234° T
6. 059° T	7. 085° T	8. 200° T		

Exercise 1.4.1

1. 057°	2. 125°	3. 247°	4. 322°	5. 113°
6. 091°	7. 000°	8. 194°	9. 240°	10. 269°

Exercise 1.4.2

1. 152° T 19.6 knots	2. 296° T 13.3 knots	3. 292° T 2.8 knots
4. 343° T	5. 177° T 14.3 knots	

Exercise 1.5.1

1. 9.7 miles	2. 7.05 miles
3. Compass error 3° E. Bearing 057° T	4. 49° 54.2′ N 5° 46.7′ W
5. 49° 57.0′ N 5° 45.5′ W	6. 49° 50.0′ N 5° 43.8′ W
7. 49° 58.5′ N 7° 35.7′ W. PL 035°/215°	

Exercise 1.6.1

1. 41° 24.6′ N or S	2. 70° 31.7′ N or S
3. 9° 22′	4. 348.5 miles
5. 57° 24.6′ N or 59° 04.6′ S	6. 31° 42′ N 23° 07.8′ W
7. 50° 20.1′ N or S	8. 6° 15.1′
9. 48° 11.3′ N or S	10. 39° 00′ N 50° 19.4′ W

Exercise 1.6.2

1. 11° 08.9′	2. 49.8 miles
3. 51° 19.1′ N 28° 57.2′ N	4. 574.5 knots
5. 6° 02.2′	6. 594.9 miles
7. 20m 23.6s	

Exercise 1.6.3

1. Course N 63.9′ W distance 259 miles	2. 39° 31.5′ N 166° 11.3′ W
3. Course S 59° 465′ E distance 2620.2 miles	4. 35° 04.7′ S 176° 04.5′ W

Exercise 1.6.4

1. a. 848.9 b. 1862.0 c. 2244.1 d. 3962.7
2. Course S 30.3° W distance 2212.0 miles
3. Course S 14.2° W distance 1851.2 miles
4. Course S 60.6° E distance 6000.0 miles
5. 18° 40.5′ N 155° 30.7′ E
6. 11° 24.3′ N distance 1355.5 miles
7. 28° 51.4′ S 00° 35.5′ E
8. 33° 13.8′ N 150° 07.2′ W
9. Course S 47° 28′ E distance 2633.1 miles
10. 894.5 miles

Exercise 1.6.5

1. Initial course S 50° 39.5′ E distance 5038.6 miles

positions	45° 10.7′ S	90° W	course	S 55.9° E
	51° 52.4′ S	110° W		S 71.0° E
	54° 14.1′ S	130° W		N 87.0° E
	53° 09.9′ S	150° W		N 76.8° E
	48° 15.5′ S	170° W		N 61.2° E

2. Distance 4638.8 miles. Initial course S 33° 29.7′ W. Position of Vertex 68° 33.0′ N 58° 28.0′ E
3. Initial course N 77° 37.7′ W. Final course S 33° 29.7′ W. Distance 1732.3 miles
4. Initial course S 67° 30.3′ E. Vertex 40° 44.8′ S 20° 17′ W. Distance 3599 miles
5. Great circle distance 5190.4. Mercator distance 5594.1. Saving 403.7 miles
6. Initial course N 61° 50.5′ W. Vertex 54° 10.4′ N 160° 19.7′ W. Distance 4076.7 miles

positions	52° 24.4′ N	140° W	course	N 73° 38.4′ W
	54° 10.3′ N	160° W		N 89° 44.0′ W
	52° 31.4′ N	180°		S 74° 09.7′ W
	46° 50.1′ N	160° E		S 58° 49.7′ W

Exercise 1.6.6

1. Initial course S 54° 46.3′ E. Distance 5484.6 miles. Vertices 70° 54.9′ E and 116° 05.2′ E
2. Initial course S 73° 56.6′ E. Distance 3613.4 miles
3. Initial course S 52° 00.4′ E. Distance 5279.6 miles
4. Initial course S 69° 23.8′ W. Distance 4804.0 miles
5. Distance 6630.6. Course at equator S 48° E

Exercise 1.6.7 (Numerical answers only are given)

1. 090° or 270°
2. Vertices 42° N 40° E and 42° S 140° W Conv. 42°
4. GC Dist 3539.8m Dep 3856.7m Difference 316.9
5. Approx 085°

Exercise 1.7.1

1. LW 0135 1.2 metres, HW 0709 13.7 metres, LW 1407 0.9 metres, HW 1938 13.8 metres
2. HW 2122 14.1 metres, interval −0407, 3.05 metres
3. HW 0837 14.1 metres, interval +0247, 4.2 metres
4. 9.9 metres will not dry
5. Ht of tide 6.0 metres, interval −0330, 0822 hrs
6. Ht of tide 9.0 metres, interval −0132, 1434 hrs
7. Interval +0241 Ht of tide 8.0 metres, 53.2 metres above water

Exercise 1.7.2

1. LW 0447 0.6 metres, HW 0810 9.5 metres, LW 1715 0.6 metres, HW 2037 9.5 metres
2. HW 1931 8.2 metres, 10.7 metres
3. HW 0624 12.2 metres, LW 1231 0.4 metres, interval +0406, 2.0 metres
4. HW 0914 12.8 metres, LW 1523 0.6 metres, interval + 0246, 8.3 metres
5. Ht of tide 8.0 metres, HW 1108 10.8 metres, LW 0521 1.8 metres, interval −0220, 0848 hrs
6. Ht of tide 5.5 metres, HW 2001 11.2 metres, LW 0152 1.4 metres, interval +0320, 2321 hrs
7. HW 0823 11.3 metres, LW 1609 1.2 metres, interval +0637, 1.2 metres

Exercise 2.1.1

1. GHA 333° 28.2′ Declination 22° 23.8′ S
2. GHA 49° 02.2′ Declination 1° 29.0′ N
3. GHA 350° 23.0′ Declination 23° 24.5′ S
4. GHA 81° 20.3′ Declination 23° 16.5′ N
5. GHA 246° 23.6′ Declination 2° 37.2′ S

Exercise 2.1.2

1. GHA 144° 13.9′ Declination 8° 30.0′ S
2. GHA 30° 37.1′ Declination 26° 43.3′ N
3. GHA 335° 49.3′ Declination 9° 34.4′ S
4. GHA 341° 54.5′ Declination 0° 44.0′ S
5. GHA 346° 20.4′ Declination 16° 17.8′ S
6. GHA 271° 57.0′ Declination 16° 45.6′ N

Exercise 2.1.3

1. LHA 72° 20.2′	2. LHA 68° 59.6′	3. LHA 267° 05.4′
4. LHA 342° 14.7′	5. LHA 143° 07.3′	6. LHA 294° 22.9′
7. LHA 199° 59.2′	8. LHA 63° 39.6′	

Exercise 2.3.1

1. LHA 305° 26.1′	Angle P 54° 33.9′ T. Brg S 65.3° E	Error 9.3° W Dev 3.3° W
2. LHA 25° 09.5′	Angle P 25° 09.5′ T. Brg N 46.7° W	Error 2.3° E Dev 5.3° E
3. LHA 319° 24.0′	Angle P 40° 36.0′ T. Brg S 37.3° E	Error 15.3° W Dev 19.3° W
4. LHA 302° 54.2′	Angle P 57° 05.8′ T. Brg N 51.2° E	Error 7.8° W Dev 5.8° W
5. LHA 51° 35.0′	Angle P 51° 35.0′ T. Brg S 77.2° W	Error 5.3° W

Exercise 2.3.2

1. LHA 69° 32.4′	Angle P 69° 32.4′ T. Brg S 69.4° W	Error 19.4° E Dev 23.4° E
2. LHA 51° 23.7′	Angle P 51° 23.7′ T. Brg S 74.8° W	Error 7.8° E Dev 1.3° E
3. LHA 332° 14.5′	Angle P 27° 45.5′ T. Brg S 42.1° E	Error 2.9° E Dev 3.9° E
4. LHA 66° 02.0′	Angle P 66° 02′ T. Brg N 50.6° W	Error 6.6° W Dev 0.4° E
5. LHA 105° 44.9′	Angle P 105° 44.9′ T. Brg S 33.9° W	Error 6.1° W Dev 2.1° W

Exercise 2.3.3

1. Amplitude E 3° 00.4′ S. Compass error 4° E
2. Amplitude E 2° 12.3′ N. Compass error 2.8° E. Deviation 2.2° W
3. Amplitude W 31.3° N. Compass error 0.3° E. Deviation 6.3° E
4. Amplitude E 30.5° S. Compass error 5.5° W
5. Amplitude W 35.9° S. Compass error 0.9° High
6. Amplitude E 32.4° N. Compass error 2.4° High

Exercise 2.4.1

1. True altitude 52° 39.6′	2. True altitude 33° 20.1′	3. True altitude 71° 33.2′
4. True altitude 27° 24.1′	5. True altitude 62° 47.1′	6. True altitude 55° 33.6′

Exercise 2.4.2

1. True altitude 47° 21.8′	2. True altitude 32° 17.0′	3. True altitude 21° 05.5′
4. True altitude 47° 06.6′	5. True altitude 37° 02.3′	6. True altitude 12° 08.0′
7. True altitude 53° 14.0′	8. True altitude 23° 08.1′	9. True altitude 51° 47.5′
10. True altitude 14° 26.2′		

Exercise 2.4.3

1. True altitude 63° 52.0′	2. True altitude 35° 10.9′	3. True altitude 58° 23.3′
4. True altitude 77° 43.0′	5. True altitude 22° 32.5′	6. True altitude 39° 15.0′
7. True altitude 51° 27.6′	8. True altitude 44° 08.0′	

Exercise 2.4.4

1. True altitude 52° 39.4′	2. True altitude 33° 20.2′	3. True altitude 71° 33.3′
4. True altitude 27° 24.2′	5. True altitude 62° 46.9′	6. True altitude 55° 33.5′

Exercise 2.4.5

1. True altitude 47° 21.8′ 2. True altitude 32° 17.1′ 3. True altitude 21° 05.5′
4. True altitude 47° 06.6′ 5. True altitude 37° 02.2′ 6. True altitude 12° 08.0′
7. True altitude 53° 14.2′ 8. True altitude 23° 08.1′ 9. True altitude 51° 47.6′
10. True altitude 14° 26.3′

Exercise 2.4.6

1. True altitude 63° 52.0′ 2. True altitude 35° 10.8′ 3. True altitude 58° 22.9′
4. True altitude 77° 42.5′ 5. True altitude 22° 32.6′ 6. True altitude 39° 15.6′
7. True altitude 51° 27.1′ 8. True altitude 44° 07.9′

Exercise 2.5.1

1.	46° 55.2′ N	6° 45.6′ W	2.	36° 10.1′ S	122° 33.6′ E
3.	9° 27.3′ N	177° 47.5′ E	4.	52° 11.7′ N	164° 15.2′ W
5.	34° 14.6′ N	40° 28.3′ W	6.	10° 14.9′ S	25° 46.2′ W
7.	15° 13.8′ S	159° 17.5′ W	8.	36° 48.6′ N	147° 08.1′ E
9.	23° 45.3′ N	51° 57.4′ W	10.	7° 00.6′ S	41° 55.0′ W
11.	41° 23.4′ S	114° 36.0′ E	12.	19° 34.7′ N	161° 10.8′ W
13.	52° 37.5′ N	135° 56.8′ W	14.	52° 12.6′ N	164° 33.5′ W
15.	50° 21.8′ N	23° 45.4′ W	16.	5° 55.8′ N	88° 52.9′ E
17.	30° 30.0′ N	46° 13.6′ W	18.	32° 06.2′ S	115° 27.3′ E

Exercise 2.6.1

1. TZX 18° 42.8′ Latitude 35° 13.9′ N 2. TZX 62° 03.1′ Latitude 0° 19.5′ S
3. TZX 61° 52.7′ Latitude 49° 55.5′ S 4. TZX 18° 44.6′ Latitude 26° 56.2′ S
5. TZX 56° 02.2′ Latitude 0° 05.4′ S

Exercise 2.6.2

1. TZX 23° 41.4′ Latitude 0° 17.6′ N 2. TZX 48° 20.8′ Latitude 25° 04.3′ S
3. TZX 28° 59.0′ Latitude 51° 27.7′ S 4. TZX 39° 38.0′ Latitude 37° 04.1′ N
5. TZX 53° 12.4′ Latitude 51° 31.1′ S

Exercise 2.6.3

1. Decl. 20° 13.8′ S T. Alt. 41° 11.8′ Latitude 28° 34.4′ N
2. Decl. 26° 52.1′ N T. Alt. 30° 54.3′ Latitude 32° 13.6′ S
3. Decl. 7° 40.9′ S T. Alt. 70° 28.1′ Latitude 27° 12.8′ S
4. Decl. 23° 21.4′ S T. Alt. 68° 51.5′ Latitude 2° 12.9′ S

Exercise 2.6.4

1. True altitude 22° 08.6′ Latitude 50° 25.0′ N
2. True altitude 12° 14.9′ Latitude 52° 57.5′ N
3. True altitude 21° 40.0′ Latitude 55° 06.6′ N
4. True altitude 19° 24.3′ Latitude 49° 53.4′ S
5. True altitude 12° 48.6′ Latitude 45° 35.7′ S

Exercise 2.7.1

1. LHA 314° 14.9′ Angle P 45° 45.1′ Decl. 23° 19.2′ N T. Alt. 21° 17.8′ CZX 68° 43.8′ Int. 1.6 T. Brg. N 44.9° E ITP 29° 28.9′ S 121° 18.7′ W P/L 134.9°/314.9°

2. LHA 45° 24.6′ Angle P 45° 24.6′ Decl. 22° 13.4′ S T. Alt. 48° 36.8′ CZX 41° 17.1′ Int. 6.1 A. Brg. N 87.7° W ITP 32° 15.2′ S 48° 08.8′ W P/L 002.3°/182.3°
3. LHA 57° 58.5′ Angle P 57° 58.5′ Decl. 1° 18.1′ N T. Alt. 31° 55.8′ CZX 57° 59.1′ Int. 5.1 A. Brg. N 88.5° W ITP 00° 00.1′ S 160° 49.9′ W P/L 001.5°/181.5°
4. LHA 312° 21.9′ Angle P 47° 38.1′ Decl. 23° 23.0′ S T. Alt. 10° 30.6′ CZX 79° 40.6′ Int. 11.2 T. Brg. S 43.6° E ITP 43° 03.9′ N 38° 14.4′ W P/L 046.4°/226.4°
5. LHA 296° 17.3′ Angle P 63° 42.7′ Decl. 2° 42.2′ S T. Alt. 16° 32.9′ CZX 73° 26.5′ Int. 0.6 A. Brg. S 69.1° E ITP 44° 05.2′ N 27° 41.8′ W P/L 020.9°/200.9°

Exercise 2.7.2

1. LHA 54° 00.3′ Angle P 54° 00.3′ Decl. 19° 10.0′ N T. Alt. 39° 59.6′ CZX 50° 06.6′ Int. 6.2 T. Brg. N 84.9° W ITP 24° 30.6′ N 145° 03.2′ E P/L 005.1°/185.1°
2. LHA 77° 00.8′ Angle P 77° 00.8′ Decl. 56° 33.5′ N T. Alt. 41° 47.1′ CZX 48° 40.0′ Int. 27.1 T. Brg. N 45.7° W ITP 43° 23.9′ N 177° 42.6′ W P/L 224.3°/044.3°
3. LHA 292° 12.5′ Angle P 67° 47.5′ Decl. 8° 40.2′ S T. Alt. 17° 55.4′ CZX 71° 59.1′ Int. 5.5 A. Brg. S 74.3° E ITP 17° 55.1′ N 47° 35.6′ W P/L 015.7°/195.7°
4. LHA 303° 25.0′ Angle P 56° 35.0′ Decl. 26° 42.0′ N T. Alt. 41° 36.9′ CZX 48° 13.1′ Int. 10.0 A. Brg. S 89.8° E ITP 42° 40.0′ N 172° 23.6′ W P/L 000.2°/180.2°
5. LHA 65° 15.7′ Angle P 65° 15.7′ Decl. 5° 13.1′ N T. Alt. 14° 54.8′ CZX 75° 13.9′ Int. 8.7 T. Brg. N 69.3° W ITP 40° 56.4′ S 57° 07.8′ W P/L 200.7°/020.7°

Exercise 2.7.3

1. LHA 292° 34.2′ Angle P 67° 25.8′ Decl. 24° 59.2′ N T. Alt. 32° 48.1′ CZX 57° 09.6′ Int. 2.3 A. Brg. N 85° E ITP 42° 49.8′ N 41° 33.1′ W P/L 355°/175°
2. LHA 340° 17.2′ Angle P 19° 42.8′ Decl. 2° 54.8′ S T. Alt. 55° 38.3′ CZX 34° 14.2′ Int. 7.5 A. Brg. S 36.8° E ITP 25° 36.0′ N 174° 55.0′ E P/L 053°/233°

Exercise 2.7.4

1. GHA 348° 04.1′ TZX 58° 20.8′ LHA 59° 53.0′ Longitude 71° 48.9′ E Brg N 69° W PL 201°/011°
2. GHA 61° 58.0′ TZX 65° 50.3′ LHA 295° 03.9′ Longitude 126° 54.1′ W Brg S 82.9° E PL 007°/187°
3. GHA 136° 11.6′ TZX 46° 42.2′ LHA 307° 31.3′ Longitude 171° 19.7′ E Brg N 90° E PL 000°/180°
4. GHA 302° 42.6′ TZX 59° 59.8′ LHA 302° 35.3′ Longitude 0° 07.3′ W Brg S 63.8° E PL 026.2°/206.2°
5. GHA 320° 13.3′ TZX 70° 56.0′ LHA 300° 03.7′ Longitude 20° 09.6′ W Brg S 66.2° E PL 023.8°/203.8°

Exercise 2.7.5

1. GHA 113° 42.7′ TZX 57° 33.3′ LHA 314° 27.7′ Forenoon longitude 157° 15.0′ W Brg N 54.6° E PL 144.6°/324.6°. Noon DR 45° 54.5′ S 158° 11.2′. Longitude correction 0.2′ E. Noon position 45° 54.7′ S 158° 11.0′ W
2. GHA 150° 33.6′ TZX 72° 34.9′ LHA 319° 00.0′ Forenoon longitude 168° 26.4′ W Brg N 39.1° E PL 129.1°/309.1°. Noon DR 37° 46.7′ S 169° 02.3′. Longitude correction 11.3′ E. Noon position 37° 53.9′ S 169° 13.6′ E

Exercise 2.8.1

1. LHA ♈ 2° 55.9′ Position 49° 29.1′ N 36° 20.4′ W PL 090.6°/270.6°
2. LHA ♈ 281° 50.8′ Position 35° 27.6′ N 36° 25′ W PL 090.9°/270.9°
3. LHA ♈ 318° 15.7′ Position 47° 31.1′ N 158° 40′ W PL 091.1°/271.1°
4. LHA ♈ 84° 07.7′ Position 50° 34.1′ N 162° 10.8′ W PL 089.2°/269.2°

Paper 1

1. 281° C, 1h 42m
2. 49° 53.7′ N 5° 05.7′ W
3. 1° 27′
4. Second position 49° 54.6′ N 5° 20.4′ W, tide 330° 1.7 knots
5. 47° 03.5′ N 10° 14.3′ W
6. Course N 28½° W, distance 131.0 miles
7. Compass error 1.5° W, deviation 6.5° E

Paper 2

1. 282½°
2. 50° 16.3′ N 4° 44.6′ W, 094½° C
3. Tide 221° 1.5 knots, course and speed made good 315° 11.8 knots
4. 20.65 miles
5. 55° 17.9′ N 3° 56.1′ E
6. Compass error 7½° W, deviation 1½° W

Paper 3

1. 49° 58.5′ N 5° 44.0′ W
2. Course and distance 121° T 16.2 miles. 134½°. Steaming time 1h 58m
3. 50° 07.1′ N 5° 00.5′ W, 20° W
4. 49° 59.6′ N 5° 37.9′ W, tide 349° 2.1 knots
5. LW 0500 0.6m, HW 0824 8.7m, LW 1720 0.6m, HW 2046 8.5m

Paper 4

1. LHA 28° 24.2′, CZX 39° 33.0′, TZX 39° 26.8′, intercept 6.2′ towards, brg N 43.8° W ITP 5° 53.5′ S 125° 58.7′ E 226.2°/046.2°
2. UT 0929, LMT 1841 19th. 38° 19.3′
3. Course N 42° 50.3′ E, distance 2011.5 miles
4. LHA 336° 16.7′ Error 4° W, Deviation 3° E

Paper 5

1. LHA 56° 11.7′, CZX 55° 18.7′, TZX 55° 15.2′, intercept 3.5′ towards, brg 261½° ITP 33° 04.5′ N 131° 22.1′ W, PL 171½°/351½°
2. LHA 357° 58.9′, CZX 48° 41.5′, TZX 48° 36.3′, intercept 5.2′ towards, brg 177½°, ITP 26° 11.8′ N 48° 10.7′ W, PL 267½°/087½°
3. LHA ♈ 204° 56.0′, latitude 20° 46.8′ N, PL 269.8°/089.8°
4. 39° 15.1′ S 94° 13.2′ E

Paper 6

1. LHA 39° 07.0′, CZX 60° 30.8′, TZX 60° 37.8′, intercept 7.0′ away, brg S 46.4° W ITP 47° 34.8′ N 45° 12.5′ W, PL 136½°/316½°
2. Declination 1° 59.7′ S, latitude 51° 25.7′ N
3. 50° 30.5′ N 47° 24.5′ W
4. Declination 2° 38.0′ S, error 6° W, deviation 10° W

Paper 7

1. LHA 309° 13.6′, CZX 51° 48.9′, TZX 51° 52.4′, intercept 3.5′ away, brg 099.8°, ITP 12° 10.6′ N 50° 08.5′ W, PL 189.8°/009.8°
2. LHA 358° 15.5′, CZX 45° 03.1′, TZX 45° 13.5′, intercept 10.4′ away, brg N 2½° E ITP 38° 50.4′ S 138° 45.4′ E, PL 272½°/092½°
3. Declination 1° 01.4′ N, latitude 26° 09.8′ N, PL 090°/270°
4. 22° 33.9′ N 91° 15.1′ W

Paper 8

1. LHA 312° 56.7′, CZX 55° 28.3′, TZX 55° 15.0′, intercept 13.3′ towards, brg S 62.6° E, ITP 30° 33.9′ N 175° 31.7′ E, PL 207½°/027½°
2. Declination 22° 32.5′ S, latitude 26° 27.6′ N, PL 090°/270°
3. LHA ♈ 314° 54.8′, latitude 47° 42.7′ N, PL 091.1°/271.1°
4. 42° 03.5′ S 161° 25.0′ E

Extracts from the Nautical Almanac 2003

A2 ALTITUDE CORRECTION TABLES 10°-90°—SUN, STARS, PLANETS

OCT.—MAR. SUN App. Alt.	Lower Limb	Upper Limb	APR.—SEPT. SUN App. Alt.	Lower Limb	Upper Limb
° ′	′	′	° ′	′	′
9 34	+10·8	−21·5	9 39	+10·6	−21·2
9 45	+10·9	−21·4	9 51	+10·7	−21·1
9 56	+11·0	−21·3	10 03	+10·8	−21·0
10 08	+11·1	−21·2	10 15	+10·9	−20·9
10 21	+11·2	−21·1	10 27	+11·0	−20·8
10 34	+11·3	−21·0	10 40	+11·1	−20·7
10 47	+11·4	−20·9	10 54	+11·2	−20·6
11 01	+11·5	−20·8	11 08	+11·3	−20·5
11 15	+11·6	−20·7	11 23	+11·4	−20·4
11 30	+11·7	−20·6	11 38	+11·5	−20·3
11 46	+11·8	−20·5	11 54	+11·6	−20·2
12 02	+11·9	−20·4	12 10	+11·7	−20·1
12 19	+12·0	−20·3	12 28	+11·8	−20·0
12 37	+12·1	−20·2	12 46	+11·9	−19·9
12 55	+12·2	−20·1	13 05	+12·0	−19·8
13 14	+12·3	−20·0	13 24	+12·1	−19·7
13 35	+12·4	−19·9	13 45	+12·2	−19·6
13 56	+12·5	−19·8	14 07	+12·3	−19·5
14 18	+12·6	−19·7	14 30	+12·4	−19·4
14 42	+12·7	−19·6	14 54	+12·5	−19·3
15 06	+12·8	−19·5	15 19	+12·6	−19·2
15 32	+12·9	−19·4	15 46	+12·7	−19·1
15 59	+13·0	−19·3	16 14	+12·8	−19·0
16 28	+13·1	−19·2	16 44	+12·9	−18·9
16 59	+13·2	−19·1	17 15	+13·0	−18·8
17 32	+13·3	−19·0	17 48	+13·1	−18·7
18 06	+13·4	−18·9	18 24	+13·2	−18·6
18 42	+13·5	−18·8	19 01	+13·3	−18·5
19 21	+13·6	−18·7	19 42	+13·4	−18·4
20 03	+13·7	−18·6	20 25	+13·5	−18·3
20 48	+13·8	−18·5	21 11	+13·6	−18·2
21 35	+13·9	−18·4	22 00	+13·7	−18·1
22 26	+14·0	−18·3	22 54	+13·8	−18·0
23 22	+14·1	−18·2	23 51	+13·9	−17·9
24 21	+14·2	−18·1	24 53	+14·0	−17·8
25 26	+14·3	−18·0	26 00	+14·1	−17·7
26 36	+14·4	−17·9	27 13	+14·2	−17·6
27 52	+14·5	−17·8	28 33	+14·3	−17·5
29 15	+14·6	−17·7	30 00	+14·4	−17·4
30 46	+14·7	−17·6	31 35	+14·5	−17·3
32 26	+14·8	−17·5	33 20	+14·6	−17·2
34 17	+14·9	−17·4	35 17	+14·7	−17·1
36 20	+15·0	−17·3	37 26	+14·8	−17·0
38 36	+15·1	−17·2	39 50	+14·9	−16·9
41 08	+15·2	−17·1	42 31	+15·0	−16·8
43 59	+15·3	−17·0	45 31	+15·1	−16·7
47 10	+15·4	−16·9	48 55	+15·2	−16·6
50 46	+15·5	−16·8	52 44	+15·3	−16·5
54 49	+15·6	−16·7	57 02	+15·4	−16·4
59 23	+15·7	−16·6	61 51	+15·5	−16·3
64 30	+15·8	−16·5	67 17	+15·6	−16·2
70 12	+15·9	−16·4	73 16	+15·7	−16·1
76 26	+16·0	−16·3	79 43	+15·8	−16·0
83 05	+16·1	−16·2	86 32	+15·9	−15·9
90 00			90 00		

STARS AND PLANETS

App Alt.	Corrⁿ
° ′	′
9 56	−5·3
10 08	−5·2
10 20	−5·1
10 33	−5·0
10 46	−4·9
11 00	−4·8
11 14	−4·7
11 29	−4·6
11 45	−4·5
12 01	−4·4
12 18	−4·3
12 35	−4·2
12 54	−4·1
13 13	−4·0
13 33	−3·9
13 54	−3·8
14 16	−3·7
14 40	−3·6
15 04	−3·5
15 30	−3·4
15 57	−3·3
16 26	−3·2
16 56	−3·1
17 28	−3·0
18 02	−2·9
18 38	−2·8
19 17	−2·7
19 58	−2·6
20 42	−2·5
21 28	−2·4
22 19	−2·3
23 13	−2·2
24 11	−2·1
25 14	−2·0
26 22	−1·9
27 36	−1·8
28 56	−1·7
30 24	−1·6
32 00	−1·5
33 45	−1·4
35 40	−1·3
37 48	−1·2
40 08	−1·1
42 44	−1·0
45 36	−0·9
48 47	−0·8
52 18	−0·7
56 11	−0·6
60 28	−0·5
65 08	−0·4
70 11	−0·3
75 34	−0·2
81 13	−0·1
87 03	0·0
90 00	

App. Alt.	Additional Corrⁿ
2003	
VENUS	
Jan. 1–Feb. 20	
°	′
0	+0·2
41	+0·1
76	
Feb. 21–Dec. 31	
°	′
0	+0·1
60	
MARS	
Jan. 1–May 2 Dec. 17–Dec. 31	
°	′
0	+0·1
60	
May 3–June 26 Oct. 26–Dec. 16	
°	′
0	+0·2
41	+0·1
76	
June 27–Aug. 1 Sept. 23–Oct. 25	
°	′
0	+0·3
34	+0·2
60	+0·1
80	
Aug. 2–Sept. 22	
°	′
0	+0·4
29	+0·3
51	+0·2
68	+0·1
83	

DIP

Ht. of Eye	Corrⁿ	Ht. of Eye
m	′	ft.
2·4	−2·8	8·0
2·6	−2·9	8·6
2·8	−3·0	9·2
3·0	−3·1	9·8
3·2	−3·2	10·5
3·4	−3·3	11·2
3·6	−3·4	11·9
3·8	−3·5	12·6
4·0	−3·6	13·3
4·3	−3·7	14·1
4·5	−3·8	14·9
4·7	−3·9	15·7
5·0	−4·0	16·5
5·2	−4·1	17·4
5·5	−4·2	18·3
5·8	−4·3	19·1
6·1	−4·4	20·1
6·3	−4·5	21·0
6·6	−4·6	22·0
6·9	−4·7	22·9
7·2	−4·8	23·9
7·5	−4·9	24·9
7·9	−5·0	26·0
8·2	−5·1	27·1
8·5	−5·2	28·1
8·8	−5·3	29·2
9·2	−5·4	30·4
9·5	−5·5	31·5
9·9	−5·6	32·7
10·3	−5·7	33·9
10·6	−5·8	35·1
11·0	−5·9	36·3
11·4	−6·0	37·6
11·8	−6·1	38·9
12·2	−6·2	40·1
12·6	−6·3	41·5
13·0	−6·4	42·8
13·4	−6·5	44·2
13·8	−6·6	45·5
14·2	−6·7	46·9
14·7	−6·8	48·4
15·1	−6·9	49·8
15·5	−7·0	51·3
16·0	−7·1	52·8
16·5	−7·2	54·3
16·9	−7·3	55·8
17·4	−7·4	57·4
17·9	−7·5	58·9
18·4	−7·6	60·5
18·8	−7·7	62·1
19·3	−7·8	63·8
19·8	−7·9	65·4
20·4	−8·0	67·1
20·9	−8·1	68·8
21·4		70·5

Ht. of Eye	Corrⁿ
m	′
1·0	− 1·8
1·5	− 2·2
2·0	− 2·5
2·5	− 2·8
3·0	− 3·0
See table ←	
m	′
20	− 7·9
22	− 8·3
24	− 8·6
26	− 9·0
28	− 9·3
30	− 9·6
32	−10·0
34	−10·3
36	−10·6
38	−10·8
40	−11·1
42	−11·4
44	−11·7
46	−11·9
48	−12·2
ft.	′
2	− 1·4
4	− 1·9
6	− 2·4
8	− 2·7
10	− 3·1
See table ←	
ft.	′
70	− 8·1
75	− 8·4
80	− 8·7
85	− 8·9
90	− 9·2
95	− 9·5
100	− 9·7
105	− 9·9
110	−10·2
115	−10·4
120	−10·6
125	−10·8
130	−11·1
135	−11·3
140	−11·5
145	−11·7
150	−11·9
155	−12·1

App. Alt. = Apparent altitude = Sextant altitude corrected for index error and dip.

UT d	UT h	ARIES GHA	VENUS −4.5 GHA	VENUS Dec	MARS +1.5 GHA	MARS Dec	JUPITER −2.5 GHA	JUPITER Dec	SATURN −0.4 GHA	SATURN Dec
		° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
4	00	103 11.4	228 06.3	S15 53.9	233 55.9	S17 30.1	323 52.3	N16 36.0	19 25.9	N22 02.2
	01	118 13.9	243 06.3	54.4	248 56.8	30.5	338 55.0	36.1	34 28.6	02.2
	02	133 16.4	258 06.3	55.0	263 57.6	30.9	353 57.7	36.2	49 31.2	02.2
	03	148 18.8	273 06.3	. . 55.5	278 58.4	. . 31.4	9 00.4	. . 36.3	64 33.9	. . 02.2
	04	163 21.3	288 06.4	56.0	293 59.3	31.8	24 03.1	36.3	79 36.6	02.2
	05	178 23.7	303 06.4	56.6	309 00.1	32.3	39 05.8	36.4	94 39.2	02.2
	06	193 26.2	318 06.4	S15 57.1	324 01.0	S17 32.7	54 08.4	N16 36.5	109 41.9	N22 02.2
	07	208 28.7	333 06.4	57.7	339 01.8	33.1	69 11.1	36.6	124 44.6	02.2
S	08	223 31.1	348 06.4	58.2	354 02.6	33.6	84 13.8	36.7	139 47.2	02.2
A	09	238 33.6	3 06.5	. . 58.8	9 03.5	. . 34.0	99 16.5	. . 36.7	154 49.9	. . 02.2
T	10	253 36.1	18 06.5	59.3	24 04.3	34.4	114 19.2	36.8	169 52.6	02.2
U	11	268 38.5	33 06.5	15 59.8	39 05.1	34.9	129 21.9	36.9	184 55.2	02.2
R	12	283 41.0	48 06.5	S16 00.4	54 06.0	S17 35.3	144 24.6	N16 37.0	199 57.9	N22 02.2
D	13	298 43.5	63 06.5	00.9	69 06.8	35.8	159 27.3	37.1	215 00.6	02.2
A	14	313 45.9	78 06.5	01.5	84 07.7	36.2	174 30.0	37.1	230 03.2	02.2
Y	15	328 48.4	93 06.5	. . 02.0	99 08.5	. . 36.6	189 32.7	. . 37.2	245 05.9	. . 02.2
	16	343 50.9	108 06.5	02.5	114 09.3	37.1	204 35.4	37.3	260 08.6	02.2
	17	358 53.3	123 06.5	03.1	129 10.2	37.5	219 38.1	37.4	275 11.2	02.2
	18	13 55.8	138 06.5	S16 03.6	144 11.0	S17 37.9	234 40.8	N16 37.5	290 13.9	N22 02.2
	19	28 58.2	153 06.6	04.2	159 11.8	38.4	249 43.5	37.5	305 16.6	02.2
	20	44 00.7	168 06.6	04.7	174 12.7	38.8	264 46.2	37.6	320 19.2	02.2
	21	59 03.2	183 06.6	. . 05.3	189 13.5	. . 39.2	279 48.9	. . 37.7	335 21.9	. . 02.2
	22	74 05.6	198 06.6	05.8	204 14.3	39.7	294 51.6	37.8	350 24.6	02.2
	23	89 08.1	213 06.6	06.3	219 15.2	40.1	309 54.3	37.9	5 27.2	02.2
5	00	104 10.6	228 06.6	S16 06.9	234 16.0	S17 40.5	324 57.0	N16 37.9	20 29.9	N22 02.2
	01	119 13.0	243 06.6	07.4	249 16.8	41.0	339 59.7	38.0	35 32.6	02.2
	02	134 15.5	258 06.6	08.0	264 17.7	41.4	355 02.4	38.1	50 35.2	02.2
	03	149 18.0	273 06.6	. . 08.5	279 18.5	. . 41.8	10 05.1	. . 38.2	65 37.9	. . 02.2
	04	164 20.4	288 06.6	09.0	294 19.3	42.3	25 07.8	38.3	80 40.5	02.2
	05	179 22.9	303 06.6	09.6	309 20.2	42.7	40 10.5	38.3	95 43.2	02.2
	06	194 25.4	318 06.5	S16 10.1	324 21.0	S17 43.1	55 13.2	N16 38.4	110 45.9	N22 02.2
	07	209 27.8	333 06.5	10.7	339 21.8	43.6	70 15.9	38.5	125 48.5	02.2
	08	224 30.3	348 06.5	11.2	354 22.7	44.0	85 18.6	38.6	140 51.2	02.2
S	09	239 32.7	3 06.5	. . 11.7	9 23.5	. . 44.4	100 21.3	. . 38.7	155 53.9	. . 02.2
U	10	254 35.2	18 06.5	12.3	24 24.3	44.9	115 24.0	38.8	170 56.5	02.2
N	11	269 37.7	33 06.5	12.8	39 25.2	45.3	130 26.7	38.8	185 59.2	02.2
D	12	284 40.1	48 06.5	S16 13.4	54 26.0	S17 45.7	145 29.4	N16 38.9	201 01.9	N22 02.2
A	13	299 42.6	63 06.5	13.9	69 26.8	46.1	160 32.1	39.0	216 04.5	02.2
Y	14	314 45.1	78 06.5	14.4	84 27.7	46.6	175 34.8	39.1	231 07.2	02.2
	15	329 47.5	93 06.4	. . 15.0	99 28.5	. . 47.0	190 37.6	. . 39.2	246 09.9	. . 02.2
	16	344 50.0	108 06.4	15.5	114 29.3	47.4	205 40.3	39.2	261 12.5	02.2
	17	359 52.5	123 06.4	16.1	129 30.2	47.9	220 43.0	39.3	276 15.2	02.2
	18	14 54.9	138 06.4	S16 16.6	144 31.0	S17 48.3	235 45.7	N16 39.4	291 17.8	N22 02.2
	19	29 57.4	153 06.4	17.1	159 31.8	48.7	250 48.4	39.5	306 20.5	02.2
	20	44 59.9	168 06.4	17.7	174 32.7	49.2	265 51.1	39.6	321 23.2	02.2
	21	60 02.3	183 06.3	. . 18.2	189 33.5	. . 49.6	280 53.8	. . 39.6	336 25.8	. . 02.1
	22	75 04.8	198 06.3	18.7	204 34.3	50.0	295 56.5	39.7	351 28.5	02.1
	23	90 07.2	213 06.3	19.3	219 35.2	50.4	310 59.2	39.8	6 31.2	02.1
6	00	105 09.7	228 06.3	S16 19.8	234 36.0	S17 50.9	326 01.9	N16 39.9	21 33.8	N22 02.1
	01	120 12.2	243 06.2	20.4	249 36.8	51.3	341 04.6	40.0	36 36.5	02.1
	02	135 14.6	258 06.2	20.9	264 37.7	51.7	356 07.3	40.1	51 39.2	02.1
	03	150 17.1	273 06.2	. . 21.4	279 38.5	. . 52.2	11 10.0	. . 40.1	66 41.8	. . 02.1
	04	165 19.6	288 06.2	22.0	294 39.3	52.6	26 12.7	40.2	81 44.5	02.1
	05	180 22.0	303 06.1	22.5	309 40.2	53.0	41 15.4	40.3	96 47.1	02.1
	06	195 24.5	318 06.1	S16 23.0	324 41.0	S17 53.4	56 18.1	N16 40.4	111 49.8	N22 02.1
	07	210 27.0	333 06.1	23.6	339 41.8	53.9	71 20.9	40.5	126 52.5	02.1
	08	225 29.4	348 06.0	24.1	354 42.6	54.3	86 23.6	40.6	141 55.1	02.1
M	09	240 31.9	3 06.0	. . 24.7	9 43.5	. . 54.7	101 26.3	. . 40.6	156 57.8	. . 02.1
O	10	255 34.3	18 06.0	25.2	24 44.3	55.1	116 29.0	40.7	172 00.5	02.1
N	11	270 36.8	33 05.9	25.7	39 45.1	55.6	131 31.7	40.8	187 03.1	02.1
D	12	285 39.3	48 05.9	S16 26.3	54 46.0	S17 56.0	146 34.4	N16 40.9	202 05.8	N22 02.1
A	13	300 41.7	63 05.9	26.8	69 46.8	56.4	161 37.1	41.0	217 08.4	02.1
Y	14	315 44.2	78 05.8	27.3	84 47.6	56.8	176 39.8	41.1	232 11.1	02.1
	15	330 46.7	93 05.8	. . 27.9	99 48.5	. . 57.3	191 42.5	. . 41.1	247 13.8	. . 02.1
	16	345 49.1	108 05.7	28.4	114 49.3	57.7	206 45.2	41.2	262 16.4	02.1
	17	0 51.6	123 05.7	28.9	129 50.1	58.1	221 48.0	41.3	277 19.1	02.1
	18	15 54.1	138 05.6	S16 29.5	144 50.9	S17 58.5	236 50.7	N16 41.4	292 21.8	N22 02.1
	19	30 56.5	153 05.6	30.0	159 51.8	59.0	251 53.4	41.5	307 24.4	02.1
	20	45 59.0	168 05.6	30.6	174 52.6	59.4	266 56.1	41.5	322 27.1	02.1
	21	61 01.5	183 05.5	. . 31.1	189 53.4	17 59.8	281 58.8	. . 41.6	337 29.7	. . 02.1
	22	76 03.9	198 05.5	31.6	204 54.3	18 00.2	297 01.5	41.7	352 32.4	02.1
	23	91 06.4	213 05.4	32.2	219 55.1	S18 00.7	312 04.2	41.8	7 35.1	02.1
Mer. Pass.		h m 17 00.5	v 0.0	d 0.5	v 0.8	d 0.4	v 2.7	d 0.1	v 2.7	d 0.0

STARS

Name	SHA ° ′	Dec ° ′
Acamar	315 24.3	S40 17.8
Achernar	335 32.6	S57 13.7
Acrux	173 18.7	S63 06.6
Adhara	255 18.6	S28 58.5
Aldebaran	290 58.6	N16 30.9
Alioth	166 27.7	N55 56.4
Alkaid	153 05.4	N49 17.7
Al Na'ir	27 54.2	S46 57.1
Alnilam	275 54.4	S 1 12.0
Alphard	218 03.9	S 8 40.2
Alphecca	126 18.2	N26 42.1
Alpheratz	357 52.2	N29 06.5
Altair	62 16.6	N 8 52.5
Ankaa	353 23.7	S42 17.7
Antares	112 36.7	S26 26.3
Arcturus	146 03.3	N19 09.9
Atria	107 46.5	S69 01.8
Avior	234 20.9	S59 31.0
Bellatrix	278 40.5	N 6 21.1
Betelgeuse	271 09.9	N 7 24.5
Canopus	263 59.3	S52 41.8
Capella	280 46.2	N46 00.2
Deneb	49 37.6	N45 17.5
Denebola	182 41.9	N14 33.3
Diphda	349 04.1	S17 58.4
Dubhe	194 01.2	N61 43.9
Elnath	278 22.7	N28 36.7
Eltanin	90 50.5	N51 29.2
Enif	33 55.5	N 9 53.2
Fomalhaut	15 33.2	S29 36.7
Gacrux	172 10.3	S57 07.4
Gienah	176 00.8	S17 33.4
Hadar	149 00.0	S60 22.9
Hamal	328 10.0	N23 28.6
Kaus Aust.	83 55.1	S34 23.0
Kochab	137 20.0	N74 08.3
Markab	13 46.7	N15 13.2
Menkar	314 23.5	N 4 06.0
Menkent	148 17.5	S36 22.9
Miaplacidus	221 40.9	S69 43.5
Mirfak	308 51.9	N49 52.5
Nunki	76 08.9	S26 17.7
Peacock	53 32.6	S56 43.7
Pollux	243 37.4	N28 01.1
Procyon	245 08.0	N 5 13.1
Rasalhague	96 14.4	N12 33.4
Regulus	207 52.0	N11 57.2
Rigel	281 19.7	S 8 11.9
Rigil Kent.	140 03.6	S60 50.5
Sabik	102 22.3	S15 43.7
Schedar	349 50.2	N56 33.4
Shaula	96 33.5	S37 06.3
Sirius	258 40.7	S16 43.2
Spica	158 40.0	S11 10.5
Suhail	222 58.2	S43 26.5
Vega	80 45.0	N38 47.1
Zuben'ubi	137 14.7	S16 03.2

	SHA ° ′	Mer. Pass. h m
Venus	123 56.0	8 48
Mars	130 05.4	8 22
Jupiter	220 46.4	2 20
Saturn	276 19.3	22 34

UT d	UT h	SUN GHA	SUN Dec	MOON GHA	MOON v	MOON Dec	MOON d	MOON HP
		° ′	° ′	° ′	′	° ′	′	′
4	00	178 51.1	S22 47.1	162 27.9	6.8	S24 28.3	5.0	57.7
	01	193 50.8	46.9	176 53.7	6.8	24 23.3	5.2	57.7
	02	208 50.6	46.6	191 19.5	7.0	24 18.1	5.3	57.6
	03	223 50.3	. . 46.4	205 45.5	7.0	24 12.8	5.4	57.6
	04	238 50.0	46.1	220 11.5	7.2	24 07.4	5.6	57.6
	05	253 49.7	45.9	234 37.7	7.2	24 01.8	5.6	57.5
	06	268 49.4	S22 45.6	249 03.9	7.3	S23 56.2	5.9	57.5
	07	283 49.1	45.4	263 30.2	7.5	23 50.3	5.9	57.5
S	08	298 48.8	45.1	277 56.7	7.5	23 44.4	6.1	57.5
A	09	313 48.6	. . 44.8	292 23.2	7.6	23 38.3	6.3	57.4
T	10	328 48.3	44.6	306 49.8	7.7	23 32.0	6.3	57.4
U	11	343 48.0	44.3	321 16.5	7.8	23 25.7	6.5	57.4
R	12	358 47.7	S22 44.1	335 43.3	7.9	S23 19.2	6.6	57.3
D	13	13 47.4	43.8	350 10.2	8.0	23 12.6	6.8	57.3
A	14	28 47.1	43.5	4 37.2	8.1	23 05.8	6.8	57.3
Y	15	43 46.8	. . 43.3	19 04.3	8.2	22 59.0	7.0	57.3
	16	58 46.6	43.0	33 31.5	8.3	22 52.0	7.1	57.2
	17	73 46.3	42.7	47 58.8	8.3	22 44.9	7.3	57.2
	18	88 46.0	S22 42.5	62 26.1	8.5	S22 37.6	7.3	57.2
	19	103 45.7	42.2	76 53.6	8.6	22 30.3	7.5	57.1
	20	118 45.4	42.0	91 21.2	8.7	22 22.8	7.6	57.1
	21	133 45.1	. . 41.7	105 48.9	8.8	22 15.2	7.7	57.1
	22	148 44.9	41.4	120 16.7	9.0	22 07.5	7.8	57.0
	23	163 44.6	41.1	134 44.7	9.0	21 59.7	7.9	57.0
5	00	178 44.3	S22 40.9	149 12.7	9.1	S21 51.8	8.0	57.0
	01	193 44.0	40.6	163 40.8	9.2	21 43.8	8.2	56.9
	02	208 43.7	40.3	178 09.0	9.3	21 35.6	8.2	56.9
	03	223 43.4	. . 40.1	192 37.3	9.4	21 27.4	8.4	56.9
	04	238 43.2	39.8	207 05.7	9.6	21 19.0	8.4	56.9
	05	253 42.9	39.5	221 34.3	9.6	21 10.6	8.6	56.8
	06	268 42.6	S22 39.2	236 02.9	9.7	S21 02.0	8.7	56.8
	07	283 42.3	39.0	250 31.6	9.9	20 53.3	8.7	56.8
	08	298 42.0	38.7	265 00.5	9.9	20 44.6	8.9	56.7
S	09	313 41.7	. . 38.4	279 29.4	10.0	20 35.7	8.9	56.7
U	10	328 41.5	38.1	293 58.4	10.2	20 26.8	9.1	56.7
N	11	343 41.2	37.9	308 27.6	10.2	20 17.7	9.1	56.6
D	12	358 40.9	S22 37.6	322 56.8	10.4	S20 08.6	9.3	56.6
A	13	13 40.6	37.3	337 26.2	10.5	19 59.3	9.3	56.6
Y	14	28 40.3	37.0	351 55.7	10.5	19 50.0	9.4	56.6
	15	43 40.1	. . 36.7	6 25.2	10.7	19 40.6	9.6	56.5
	16	58 39.8	36.5	20 54.9	10.7	19 31.0	9.6	56.5
	17	73 39.5	36.2	35 24.6	10.9	19 21.4	9.6	56.5
	18	88 39.2	S22 35.9	49 54.5	11.0	S19 11.8	9.8	56.4
	19	103 38.9	35.6	64 24.5	11.0	19 02.0	9.9	56.4
	20	118 38.7	35.3	78 54.5	11.2	18 52.1	9.9	56.4
	21	133 38.4	. . 35.0	93 24.7	11.3	18 42.2	10.0	56.3
	22	148 38.1	34.8	107 55.0	11.4	18 32.2	10.1	56.3
	23	163 37.8	34.5	122 25.4	11.4	18 22.1	10.2	56.3
6	00	178 37.6	S22 34.2	136 55.8	11.6	S18 11.9	10.3	56.3
	01	193 37.3	33.9	151 26.4	11.6	18 01.6	10.3	56.2
	02	208 37.0	33.6	165 57.0	11.8	17 51.3	10.4	56.2
	03	223 36.7	. . 33.3	180 27.8	11.9	17 40.9	10.5	56.2
	04	238 36.4	33.0	194 58.7	11.9	17 30.4	10.5	56.1
	05	253 36.2	32.7	209 29.6	12.1	17 19.9	10.6	56.1
	06	268 35.9	S22 32.4	224 00.7	12.1	S17 09.3	10.7	56.1
	07	283 35.6	32.1	238 31.8	12.2	16 58.6	10.8	56.1
	08	298 35.3	31.8	253 03.0	12.4	16 47.8	10.8	56.0
M	09	313 35.1	. . 31.6	267 34.4	12.4	16 37.0	10.9	56.0
O	10	328 34.8	31.3	282 05.8	12.5	16 26.1	10.9	56.0
N	11	343 34.5	31.0	296 37.3	12.6	16 15.2	11.0	55.9
D	12	358 34.2	S22 30.7	311 08.9	12.7	S16 04.2	11.1	55.9
A	13	13 33.9	30.4	325 40.6	12.8	15 53.1	11.2	55.9
Y	14	28 33.7	30.1	340 12.4	12.9	15 41.9	11.2	55.9
	15	43 33.4	. . 29.8	354 44.3	13.0	15 30.7	11.2	55.8
	16	58 33.1	29.5	9 16.3	13.0	15 19.5	11.3	55.8
	17	73 32.8	29.2	23 48.3	13.1	15 08.2	11.4	55.8
	18	88 32.6	S22 28.9	38 20.4	13.3	S14 56.8	11.4	55.7
	19	103 32.3	28.6	52 52.7	13.3	14 45.4	11.5	55.7
	20	118 32.0	28.3	67 25.0	13.4	14 33.9	11.5	55.7
	21	133 31.7	. . 28.0	81 57.4	13.5	14 22.4	11.6	55.7
	22	148 31.5	27.6	96 29.9	13.5	14 10.8	11.6	55.6
	23	163 31.2	27.3	111 02.4	13.6	S13 59.2	11.7	55.6
		SD 16.3	d 0.3	SD	15.6	15.4		15.2

Lat.	Twilight Naut.	Twilight Civil	Sunrise	Moonrise 4	Moonrise 5	Moonrise 6	Moonrise 7
°	h m	h m	h m	h m	h m	h m	h m
N 72	08 20	10 31	▬	▬	▬	13 24	12 33
N 70	08 02	09 43	▬	▬	14 12	12 46	12 15
68	07 47	09 13	11 32	▬	12 51	12 19	12 00
66	07 35	08 50	10 21	12 43	12 12	11 58	11 48
64	07 25	08 32	09 45	11 48	11 45	11 42	11 38
62	07 16	08 17	09 20	11 15	11 24	11 28	11 29
60	07 08	08 04	09 00	10 51	11 07	11 16	11 22
N 58	07 01	07 53	08 44	10 31	10 52	11 06	11 15
56	06 55	07 44	08 30	10 15	10 40	10 57	11 09
54	06 49	07 35	08 18	10 01	10 29	10 49	11 04
52	06 44	07 27	08 07	09 49	10 19	10 42	10 59
50	06 39	07 20	07 58	09 38	10 11	10 35	10 55
45	06 28	07 05	07 38	09 16	09 52	10 21	10 45
N 40	06 18	06 52	07 22	08 57	09 37	10 10	10 37
35	06 09	06 41	07 09	08 42	09 24	10 00	10 30
30	06 01	06 30	06 57	08 29	09 13	09 51	10 24
20	05 45	06 12	06 36	08 06	08 54	09 36	10 14
N 10	05 29	05 56	06 18	07 46	08 37	09 23	10 05
0	05 13	05 39	06 02	07 28	08 21	09 11	09 56
S 10	04 55	05 22	05 45	07 09	08 05	08 58	09 47
20	04 33	05 02	05 26	06 49	07 48	08 45	09 38
30	04 05	04 38	05 05	06 26	07 29	08 29	09 27
35	03 47	04 23	04 53	06 13	07 17	08 20	09 21
40	03 25	04 06	04 38	05 57	07 04	08 10	09 14
45	02 55	03 44	04 21	05 38	06 48	07 58	09 06
S 50	02 13	03 16	03 59	05 15	06 29	07 43	08 56
52	01 48	03 01	03 49	05 04	06 20	07 37	08 51
54	01 11	02 45	03 37	04 51	06 10	07 29	08 46
56	////	02 24	03 24	04 36	05 58	07 20	08 40
58	////	01 57	03 08	04 19	05 44	07 11	08 34
S 60	////	01 18	02 49	03 57	05 28	06 59	08 26

Lat.	Sunset	Twilight Civil	Twilight Naut.	Moonset 4	Moonset 5	Moonset 6	Moonset 7
°	h m	h m	h m	h m	h m	h m	h m
N 72	▬	13 40	15 51	▬	▬	17 41	20 04
N 70	▬	14 28	16 09	▬	15 11	18 17	20 20
68	12 39	14 58	16 24	▬	16 31	18 43	20 33
66	13 50	15 21	16 36	14 49	17 09	19 02	20 44
64	14 26	15 39	16 46	15 43	17 35	19 18	20 53
62	14 51	15 54	16 55	16 15	17 55	19 30	21 00
60	15 11	16 07	17 03	16 39	18 11	19 41	21 07
N 58	15 27	16 18	17 10	16 58	18 25	19 51	21 12
56	15 41	16 27	17 16	17 14	18 37	19 59	21 17
54	15 53	16 36	17 22	17 27	18 47	20 06	21 22
52	16 03	16 44	17 27	17 39	18 56	20 12	21 26
50	16 13	16 51	17 32	17 50	19 05	20 18	21 29
45	16 33	17 06	17 43	18 11	19 22	20 31	21 37
N 40	16 49	17 19	17 53	18 29	19 36	20 41	21 44
35	17 02	17 30	18 02	18 44	19 48	20 50	21 49
30	17 14	17 40	18 10	18 56	19 58	20 58	21 54
20	17 34	17 58	18 26	19 18	20 16	21 11	22 02
N 10	17 52	18 15	18 41	19 36	20 31	21 22	22 10
0	18 09	18 31	18 57	19 54	20 45	21 33	22 17
S 10	18 26	18 49	19 16	20 11	21 00	21 43	22 23
20	18 44	19 09	19 37	20 29	21 15	21 55	22 31
30	19 05	19 33	20 05	20 50	21 32	22 07	22 39
35	19 18	19 47	20 23	21 03	21 42	22 15	22 43
40	19 32	20 05	20 45	21 17	21 53	22 23	22 49
45	19 49	20 26	21 14	21 33	22 06	22 32	22 55
S 50	20 11	20 54	21 57	21 54	22 22	22 44	23 02
52	20 21	21 08	22 21	22 03	22 30	22 49	23 05
54	20 33	21 25	22 57	22 14	22 38	22 55	23 09
56	20 46	21 45	////	22 26	22 47	23 02	23 13
58	21 02	22 12	////	22 41	22 58	23 09	23 17
S 60	21 20	22 50	////	22 57	23 10	23 17	23 22

Day	SUN Eqn. of Time 00h	SUN Eqn. of Time 12h	SUN Mer. Pass.	MOON Mer. Pass. Upper	MOON Mer. Pass. Lower	MOON Age	MOON Phase
d	m s	m s	h m	h m	h m	d	%
4	04 35	04 49	12 05	13 41	01 13	02	3
5	05 02	05 16	12 05	14 33	02 08	03	8
6	05 29	05 43	12 06	15 22	02 58	04	15