PRACTICAL NAVIGATION

NUTSHELL SERIES

BOOK 1

BY

CAPT. H. SUBRAMANIAM

EXTRA MASTER, F.R.MetS., M.R.I.N., F.N.I., M.I.Mar.Tech, M.I.Met.S.,

Principal,
L.B.S. College of Advanced Maritime Studies & Research,
Bombay.

Preparation: Farzad Jadidi
Mahdi Bordbar
(Deck Cadets)

VIJAYA PUBLICATIONS

2 CHAITRA, 550 ELEVENTH ROAD,
CHEMBUR, BOMBAY 400 071

Dedicated to my mother, without whose patient and constant encouragement, this book would not have been possible.

INDIAN NATIONAL SHIPOWNERS ASSOCIATION
Grams: 'Hindships' Scindia House, Ballard Estate,
Capt. J. C. ANAND Bombay 400038
President. 18th May 1976

FOREWORD

Indian Merchant Marine and the other allied fields offer to our national talent ample opportunities to satisfy the ambitions for self-advancement and self-fulfilment without having to subordinate personality or the desire for dedication to the national service. Today our maritime technical personnel are hailed everywhere in the world as the best, and form the backbone of our national shipping. We achieved this success because of the ready availability of trained technical personnel for efficient manning and operation of the shipping industry for which one cannot but thank the silent service effectively being rendered by the LBS Nautical & Engg College, the T.S. Rajendra (which has replaced the T.S. Dufferin), the Directorate of Marine Engineering Training and the ratings training establishments to produce the most competent and disciplined floating personnel we have today - navigating and engineering officers and men - who are a pride of the nation.

Capt. H. Subramaniam, the author of this book, has to his credit a brilliant 'Dufferin' career and subsequent service with the Scindia Steam Navigation Company. This book presents to the students, the deep knowledge of the subject gained by his long personal experience whilst at sea and whilst teaching in the Nautical College. It is the first text book in his 'Nutshell Series' for nautical students and is intended to prepare students for any grade of M.O.T. examination from Mate (Home Trade) to First Mate (Foreign Going). Its special and distinctive feature is the facility it affords to the students for study while at sea, so that

PREFACE TO THE THIRD EDITION

The overwhelming response, in India and abroad, to the 'Nutshell Series' of books, especially this first one - Practical Navigation - has encouraged me to keep thinking of various ways by which improvements could be made with each subsequent edition.

In this edition, sufficient theory has been added to make the student understand the subject of Practical Navigation better than was possible with the previous editions.

Working with the help of Nautical Tables has been retained but the use of a simple, scientific, electronic calculator has been illustrated and encouraged throughout.

Since the subject of 'Spherical Trigonometry' has been covered by 'Nutshell Series' book number eight, the descriptions of steps in the chapters on Great Circle and Composite Circle Sailing have been suitably reduced.

Bombay
1st December 1995

H. Subramaniam.

they can utilise their leisure time on board more gainfully towards self advancement and save on the examination leave time.

The excellent treatment and layout of the subject gives scope for firm grounding in the science of navigation, which is so very necessary for the navigator as he has in his care, safe conduct of a modern sophisticated vessel costing crores of Rupees of capital investment and carrying valuable cargoes worth many more crores, besides the reputation of the owners and safety of several lives on board. He has to operate on the high seas amidst all nature of currents and swell, shallow or deep water, narrow or wide sea lanes, straight or sharp courses, thin or thick traffic, different conditions of weather and visibility, etc. Therefore, the need for human expertise, skill and care remain paramount. Navigation of modern ships is a science calling for theoretical and practical knowledge of the highest order to enable the navigator to meet all eventualities and emergencies at sea. The responsibility carries with it the need for instantaneous, instinctive and correct reactions to meet the situations as they arrive. That is where the student's responsibility while under training, comes in and Capt. Subramaniam's 'Practical Navigation' offer a useful aid to this end. It is a pioneering project that is most commendable and in line with the noble calling of teaching that he is pursuing at great monetary sacrifice. I would like to offer him congratulations from the shipping industry and my own self, for this most worthy effort.

Welcoming this first book of the series planned by him, I wish this and subsequent publications brilliant success as envisaged above.

(J.C. Anand).

CONTENTS

		Page
	Recommended terms and abbreviations	1
1	Terrestrial references	3
2	Celestial references	8
3	Figure drawing	15
4	Preliminary calculations	20
5	Plane and parallel sailing	25
	Exercise 1 - Plane & parallel sailing	30
6	Use of Traverse Tables	31
	Exercise 2 - Use of Traverse Tables	39
7	The Mercator Chart	40
8	Mercator sailing	44
	Exercise 3 - Mercator Sailing	47
9	Correction of altitudes - theory	48
10	Correction of altitudes - practical	52
11	Days work	57
12	Chronometer time	68
	Exercise 4 - Chronometer error	74
13	Theory of astronomical position lines	75
14	SUN - worked examples and exercises	
	14.1 - Meridian altitude	84
	14.2 - Azimuth	87
	14.3 - Amplitude	89
	14.4 - Longitude by chronometer	91
	14.5 - Intercept	95
	14.6 - Ex-meridian	99
15	STARS - worked examples and exercises	
	15.1 - Meridian altitude	103
	15.2 - Azimuth	105
	15.3 - Longitude by chronometer	108
	15.4 - Intercept	112
	15.5 - Ex-meridian	115
	15.6 - Polaris	118

16 PLANETS - worked examples and exercises
16.1 - Meridian altitude 121
16.2 - Azimuth 124
16.3 - Longitude by chronometer 126
16.4 - Intercept 129
16.5 - Ex-meridian 133
17 MOON - worked examples and exercises
17.1 - Amplitude 136
17.2 - Meridian altitude 139
17.3 - Azimuth 140
17.4 - Longitude by chronometer 142
17.5 - Intercept 146
17.6 - Ex-meridian 149
18 Graphical combination of sights
A - Simultaneous observations 153
B - Staggered observations 165
19 Correction of simple errors in sights 175
Exercise 28 - Errors in sights 182
20 Computation of altitudes 183
Exercise 29 - altitude computation 187
21 Star identification 188
Exercise 30 - star identification 192
22 Great Circle Sailing 193
Exercise 31 - great circle sailing 208
23 Composite Circle Sailing 209
Exercise 32 - composite circle sailing 212
24 Altitude Above and below the pole 213
25 Stars suitable for observation 221
Exercise 33 - suitable stars 224
Answers 225
Summary of formulae for use by calculator 234

RECOMMENDED TERMS AND ABBREVIATIONS

TERMS:

(a) Dead reckoning (or DR) position is that obtained by allowing for courses and distances only.

(b) Estimated position (or EP) is that obtained by allowing for courses and distances and also for estimated leeway and current, if any.

(c) Chosen position (or CP) is that position, nearest to the observer, chosen so that the latitude is an integral degree and the longitude is such that the local hour angle of the body at the time of the observation is also an integral degree.

(d) Sextant altitude is that read off a sextant.

(e) Observed altitude is the sextant altitude corrected for index error, if any.

ABBREVIATIONS

Latitude	lat	Course	Co
Co-latitude	Co-lat	Gyro	G

Mean latitude	m'lat	Magnetic	(M)
Diff of lat	d'lat	Compass	C
Longitude	long	True	T
Diff of long	d'long	Deviation	Dev
Meridian	mer	Variation	Var
Meridian passage	mer pass	Compass error	CE
Meridional parts	MP	Bearing	brg
Difference of MP	DMP	Distance	dist
DR position	DR	Nautical miles	M
Estimated position	EP	Knots	Kn
Geogr. position	GP	Altitude	alt
Sextant altitude	Sext alt	Departure	dep
Observed altitude	Obs alt	Days	d
Apparent altitude	App alt	Hours	h
True altitude	T alt	Minutes	m
Tabulated altitude	tab alt	Seconds	s
Calculated ZD	CZD	Zenith distance	ZD
Int terminal point	ITP	True ZD	TZD
Chronometer	chron	Intercept	Int
Local mean time	LMT	Zone time	ZT
Greenwich mean time	GMT	Hour angle	HA
Greenwich hour angle	GHA	Declination	dec
Local hour angle	LHA	Polar distance	PD
Sidereal hour angle	SHA	Rational horizon	RH
First Point of Aries	♈	Star	☆
Parallax in alt	Plx in alt	Lower limb	LL
Horizontal parallax	HP	Upper limb	UL
Azimuth	Az	Semi-diameter	SD
Position line	PL	Index error	IE
Amplitude	Amp	Refraction	refr
Traverse tables	TT	Height of eye	HE
Nautical almanac	NA	Correction	Corrn
Northern hemisphere	NH	Metres	m
Southern hemisphere	SH	Kilometres	km

1

TERRESTRIAL

REFERENCES

GEOGRAPHIC POLES

The two points where the axis of rotation cuts the surface of the earth are called the geographic poles - the upper one is called the North pole and the lower, the South Pole.

EQUATOR

The equator is a great circle which is equidistant from, and therefore 90° away from, the geographic poles. The equator divides the earth into two hemispheres - the Northern Hemisphere and the Southern Hemisphere.

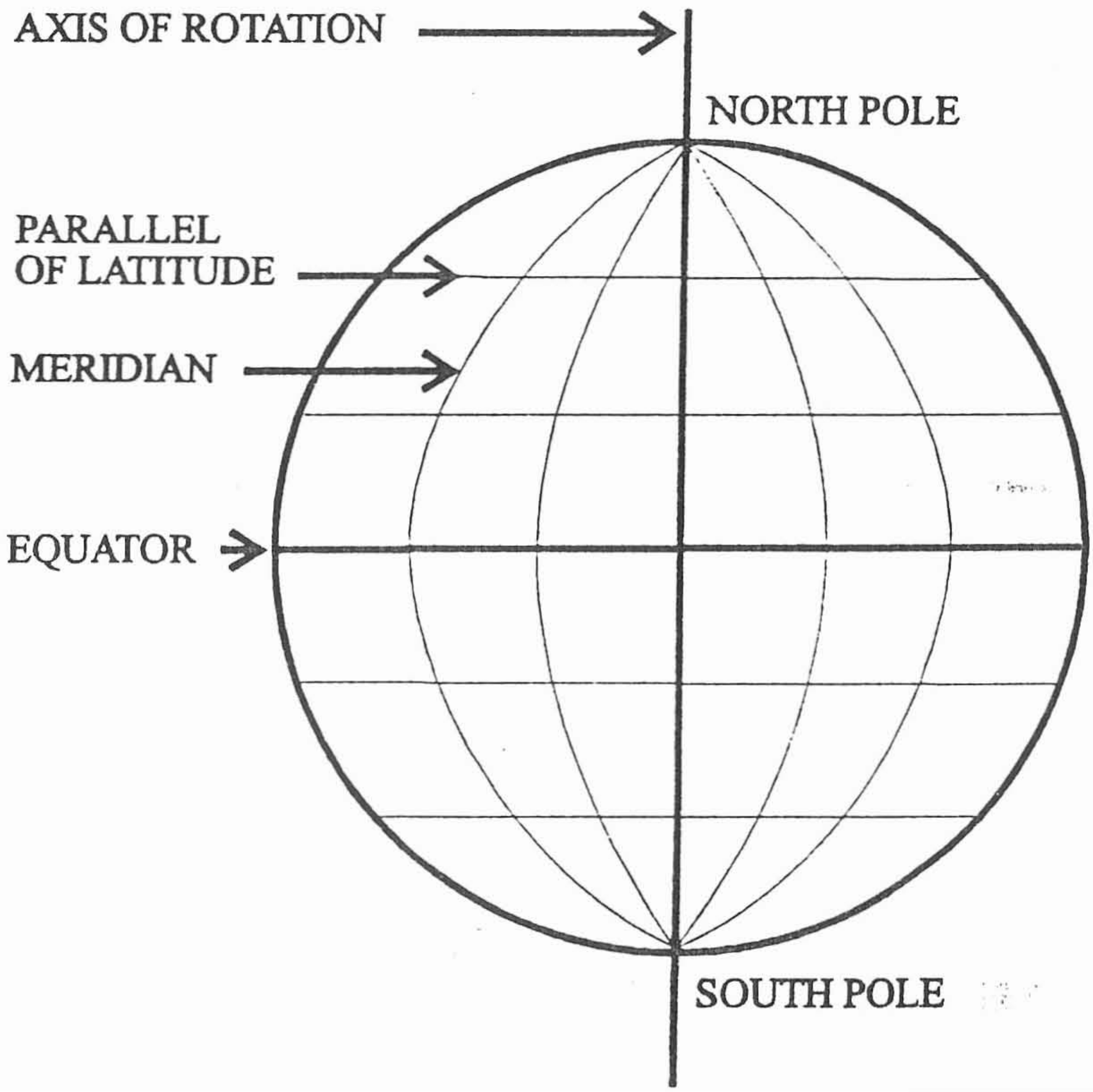
PARALLELS OF LATITUDE

Parallels of latitude are small circles parallel to the equator.

MERIDIANS OF LONGITUDE

Meridians are great circles that pass through the geographic poles. Meridians cross the equator and all parallels of latitude at right angles.

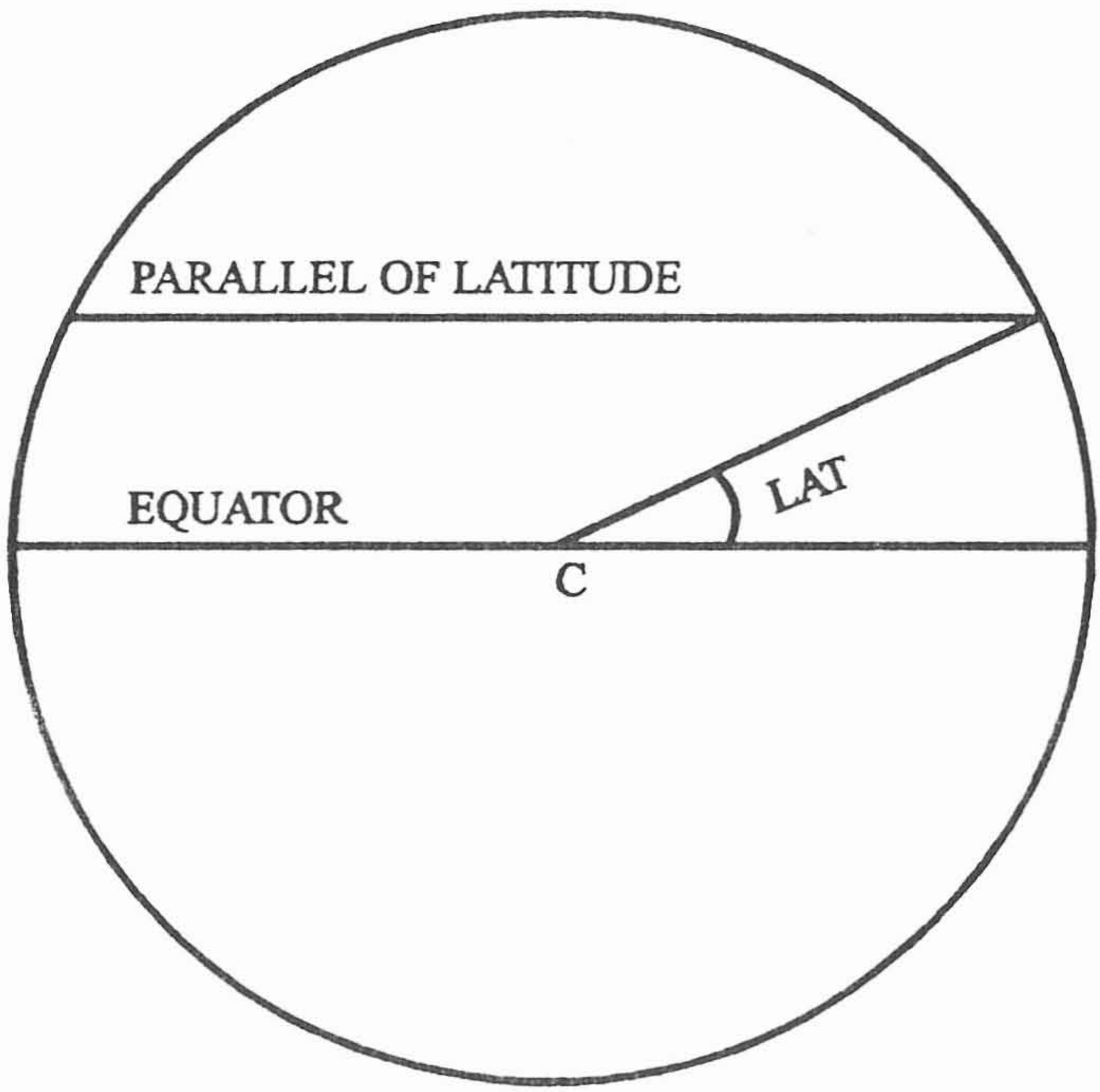
[Figure showing axis, poles, equator, parallels of lat, meridians.]



LATITUDE

Latitude of a place is the arc of a meridian, or the angle at the centre of the earth, measured between the equator and the parallel of latitude passing through that place. Latitude is expressed in degrees and minutes North or South of the equator. The latitude of a place can have any value between 0° and 90° N or S. The latitude of the North Pole is 90°N and that of the South Pole, 90°S.

[Figure showing latitude]



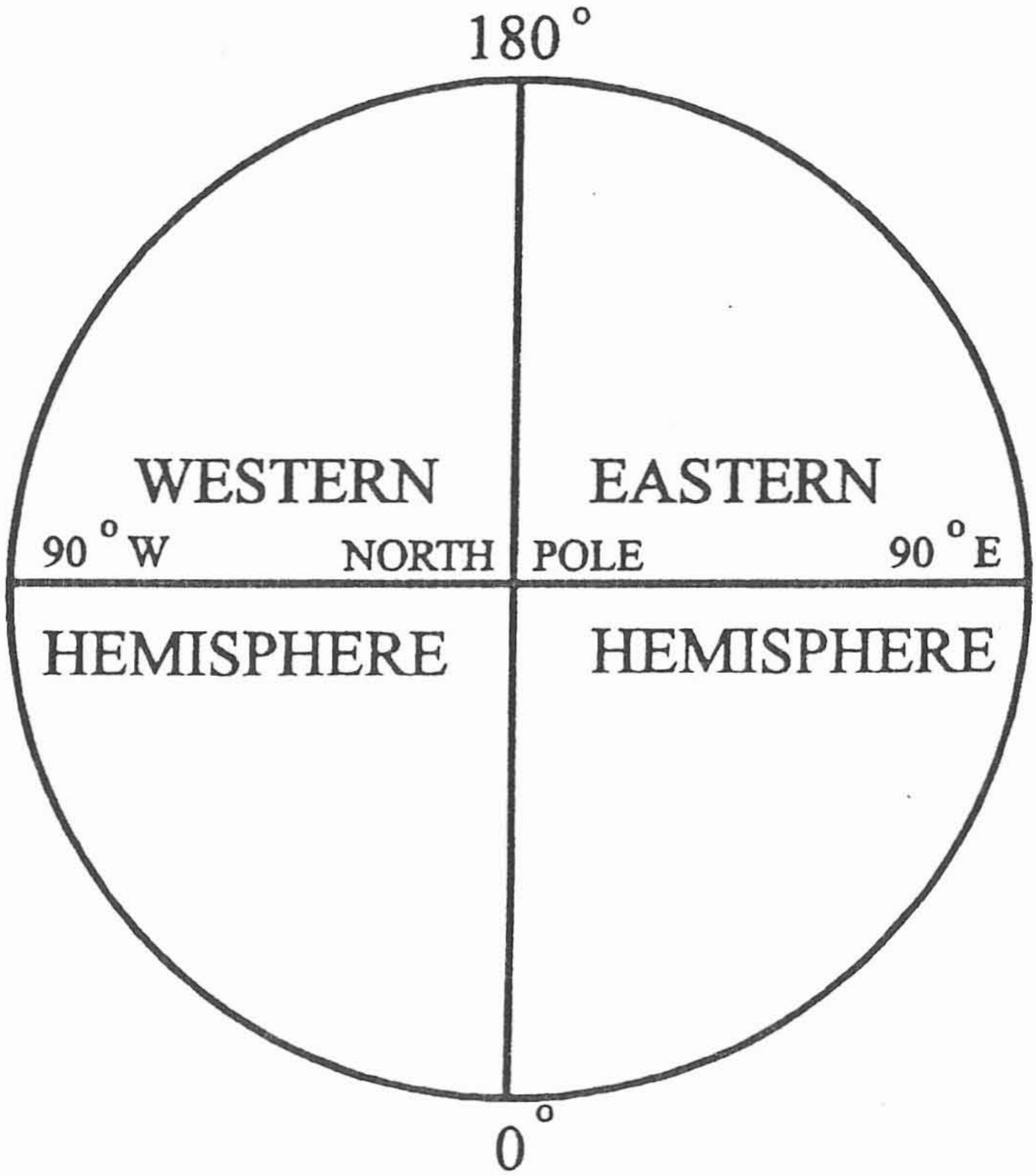
PRIME MERIDIAN

The meridian which passes through Greenwich is called the Prime Meridian and has the value of 0° of longitude.

LONGITUDE

Longitude of a place is the arc of the equator, or the angle at the geographic pole, contained between the Prime Meridian and the meridian passing through that place. Longitude is expressed in degrees and minutes East or West of Greenwich. Longitude of a place can have any value between 0° and 180°. Longitude 180°E and 180°W refer to the same meridian.

[Plan view showing 0° - 180° longitude E & W]



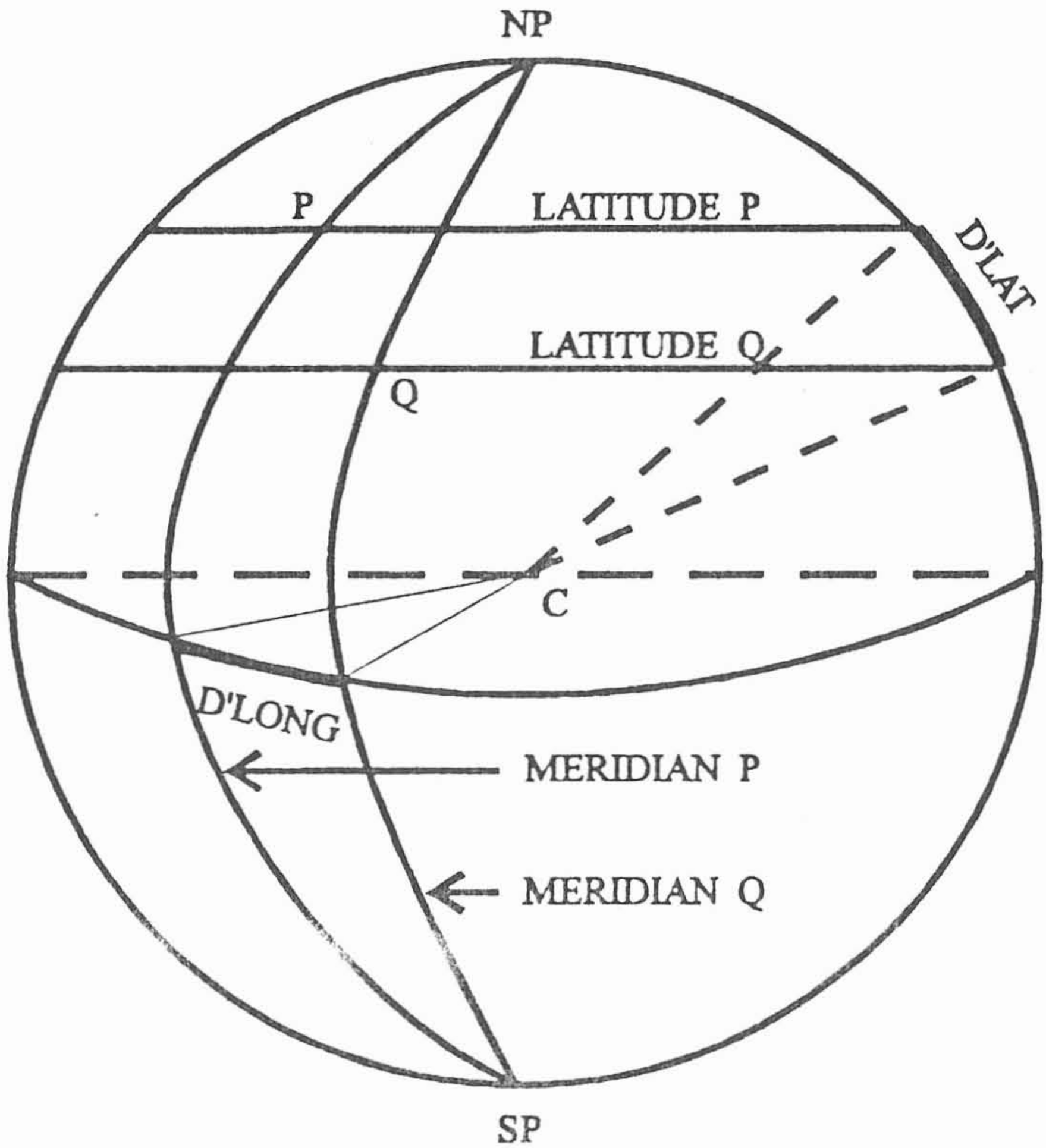
POSITION OF OBSERVER

The position of any place or person is indicated by Latitude and Longitude. For example:- 18° 58.2'N 172° 52.7'E.

D'LAT

Difference of latitude or d'lat between two places is the arc of a meridian, or the angle at the centre of the earth, contained between the parallels of latitude passing through those two places.

[Figure showing d'lat & d'long]



D'LONG

Difference of longitude or d'long between two places is the arc of the equator, or the angle at the geographic pole, contained between the meridians passing through those two places.

M'LAT

Mean latitude or m'lat between two places is that parallel of latitude which lies midway between the parallels of latitude of those two places.

2

CELESTIAL REFERENCES

THE CELESTIAL SPHERE

For the purposes of astronomical navigation, the earth is assumed to be surrounded by a concentric sphere, of infinite radius, called the Celestial Sphere. All astronomical bodies such as the Sun, Moon, stars and planets are assumed to lie on the surface of the celestial sphere. Since all calculations are based on angular measurements, the radius of the celestial sphere is irrelevant. The earth is assumed to be stationary while the celestial bodies are assumed to move on the surface of the celestial sphere.

If the earth were to be transparent, and a source of light were to be installed at its centre, the projections of the various reference points/lines on the earth would have equivalent points/lines on the surface of the celestial sphere. For example:

EARTH	CELESTIAL SPHERE
Geographic poles	Celestial poles
Equator	Equinoctial
Meridians	Celestial meridians
Parallels of lat	Declination circles
Position of observer	Zenith of observer

CELESTIAL POLES

The two points where the axis of rotation of the earth cuts the surface of the celestial sphere are called the celestial poles.

EQUINOCTIAL

The equinoctial is a great circle which is equidistant from, and therefore 90° away from, the celestial poles. The equinoctial is also referred to as the celestial equator.

DECLINATION CIRCLES

Declination circles are small circles, on the celestial sphere, parallel to the equinoctial.

CELESTIAL MERIDIANS

Celestial meridians are great circles that pass through the celestial poles. Celestial meridians cross the equinoctial and all declination circles at right angles.

DECLINATION

Declination of a celestial body is the arc of a celestial meridian, or the angle at the centre of the celestial sphere, measured between the equinoctial and the declination circle passing through that body. Declination is expressed in degrees and minutes North or South of the equinoctial. The declination of a celestial body must have a value between 0° and 90° N or S.

GHA

Greenwich Hour Angle or GHA of a celestial body is the arc of the equinoctial. or the angle at the celestial pole, measured

westerly from the celestial meridian of Greenwich to the celestial meridian passing through that body. GHA is expressed in degrees and minutes from 0° to 360°. GHA of a celestial body would increase steadily from 0° to 360°. GHA would be 0° when the body is on the Greenwich Meridian, increase steadily until it is 360° (i.e. 0°) when it would again be on the Greenwich meridian.

POSITION OF A CELESTIAL BODY

At any instant, the position of a celestial body is indicated by its declination and GHA at that instant.

LHA

Local Hour Angle or LHA of a celestial body is the arc of the equinoctial, or the angle at the celestial pole, measured westerly from the observer's celestial meridian to the celestial meridian passing through that body. Like GHA, LHA of a celestial body would increase steadily from 0° to 360°. LHA would be 0° when the body is on the observer's meridian and steadily increase until it is 360° (i.e. 0°) when it would again be on the observer's meridian. At any instant, for any celestial body :

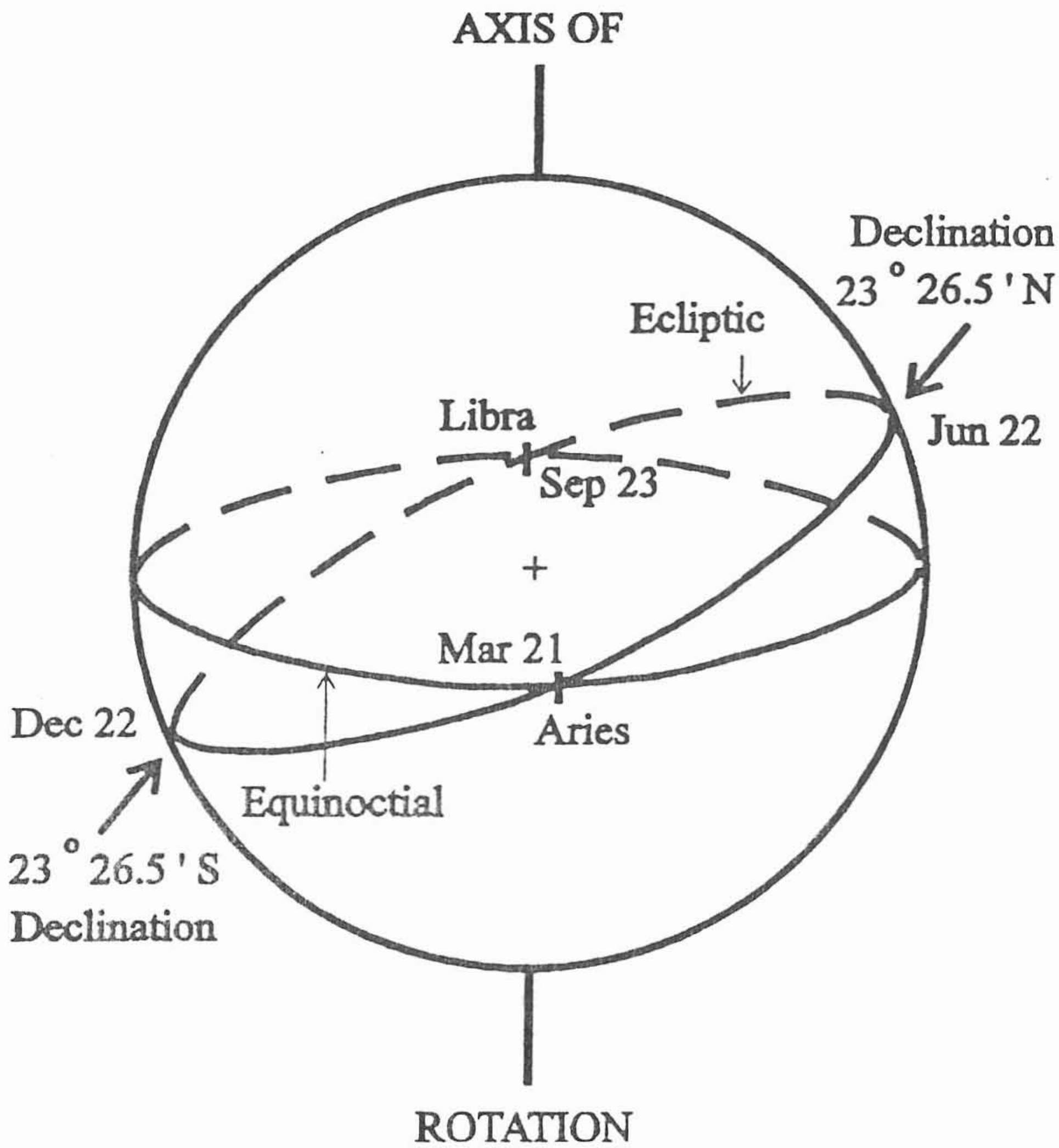
$$\text{LHA} = \text{GHA} \pm \text{Longitude of Observer}$$

The actual calculations involving GHA, LHA and longitude are explained later on in this book.

THE SUN'S ORBIT

As mentioned earlier, it is assumed that the earth is stationary and that all celestial bodies move along the surface of the celestial sphere. The Sun's orbit is inclined to the equinoctial by about 23° 26.5'. Maximum Northerly declination (about 23° 26.5'N) occurs around June 22nd and the maximum Southerly declination (about

[Figure showing Aries, Libra, etc.]



23° 26.5'S), around December 22nd. There are two specific reference points, on the Sun's orbit, called the First point of Aries and the First Point of Libra. They are also referred to as the equinoctial points.

GEOGRAPHICAL POSITION

The line joining a celestial body and the centre of the earth would cut the earth's surface at a point called the geographical position or GP of that body at that instant. GP is expressed in latitude and longitude. The value of declination is the latitude of the GP and the value of GHA, converted to longitude, would be the longitude of the GP. (GHA is expressed in degrees and minutes west of Greenwich from 0° to 360° whereas longitude is expressed from 0° to 180° E or W of Greenwich).

RELATIONSHIP BETWEEN ARC AND TIME

When the earth rotates on its axis once, one day has elapsed. This means that:

ARC	TIME
360°	24 hours
15°	1 hour
1°	4 minutes
1'	4 seconds

A table for converting arc to time and vice versa is given in the Nautical Almanac.

GHA and LHA, though usually expressed in degrees and minutes of arc, may also be expressed in hours, minutes and seconds of time. The symbols for degrees and minutes of arc are ° and ' whereas the symbols for time are h, m and s.

GMT

When the sun is on the Greenwich meridian, GHA = 0° but the time is said to be 1200 hours GMT. So GMT is ahead of GHA by 12 hours. GMT is the number of hours, minutes and seconds since the sun crossed the inferior meridian of Greenwich. (The

inferior meridian is one which is 180° away i.e. on the opposite side of the earth/celestial sphere).

LMT

When the sun is on the observer's meridian, LHA = 0° but the time is said to be 1200 hours LMT. So LMT is ahead of LHA by 12 hours. LMT is the number of hours, minutes and seconds since the sun crossed the inferior meridian of the observer. (The inferior meridian is one which is 180° away i.e. on the opposite side of the earth/celestial sphere).

RELATIONSHIP BETWEEN GMT & LMT

It is obvious from the foregoing that the difference of time between GMT and LMT is only longitude expressed in units of time.

$$\text{Longitude in time} = \text{GMT} \pm \text{LMT}$$

The actual calculations involving GMT, LMT and longitude are explained later on in this book.

3

FIGURE DRAWING FOR ASTRO CALCULATIONS

Imagine a globe, representing the earth, as shown in the following figure A . NP &.SP are the north and south geographic poles respectively. WQE is the equator and ll is the parallel of latitude of the observer Z. The N-S diametric line is the meridian of the observer.

If the globe is now tilted slightly towards us, the points P, Z and Q would move downwards and both, the equator and the parallel of latitude, would appear as curves. as shown in figure B. The south geographic pole would have disappeared from view. We have to bear in mind that P, Z and Q are on the surface of the globe and not on a flat surface.

If the globe is gradually tilted more and more, until Z is in transit with the centre of the globe, the globe would appear as shown in figure C. Since all the points, P, Z and Q have apparently moved only because of the tilting of the globe, each has shifted out of its original position by the same amount i.e., NP = ZQ (see figure C). But ZQ = latitude. So NP = ZQ = latitude. This can be proved mathematically as follows:

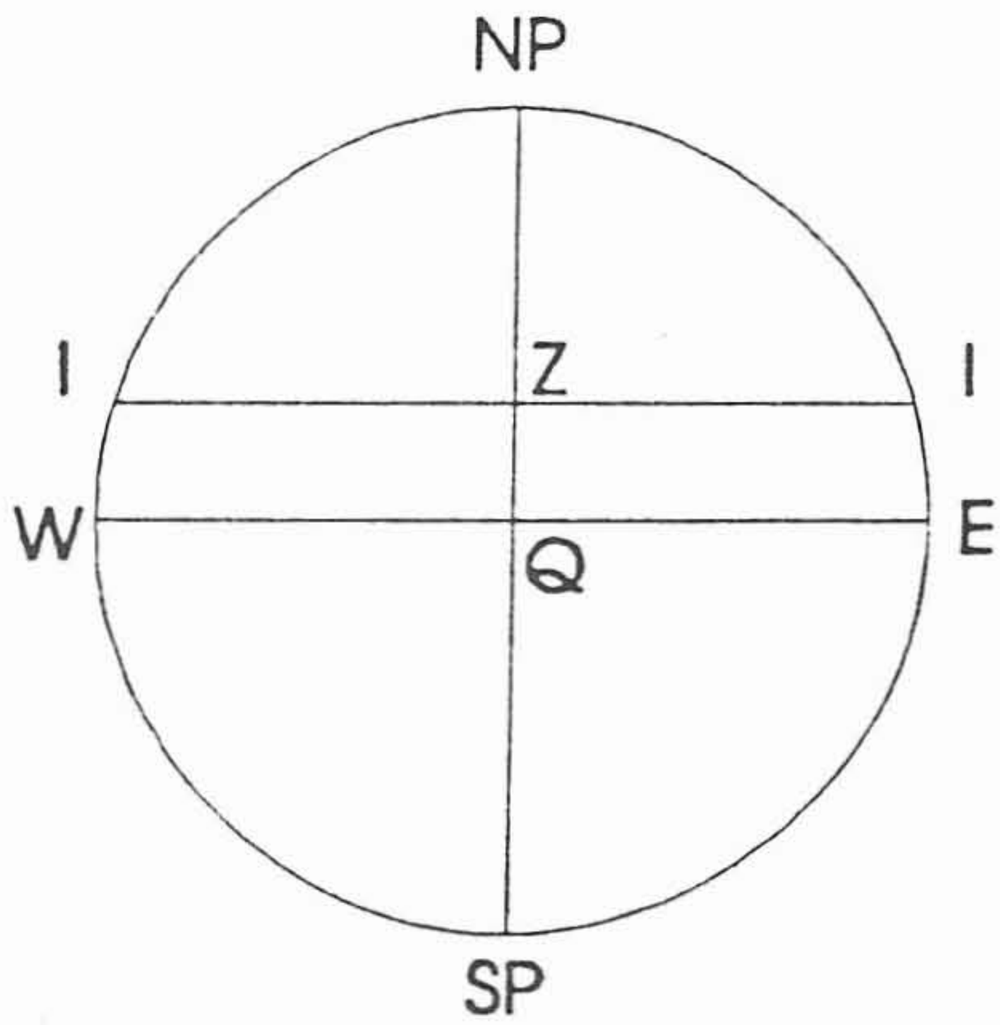


FIGURE A

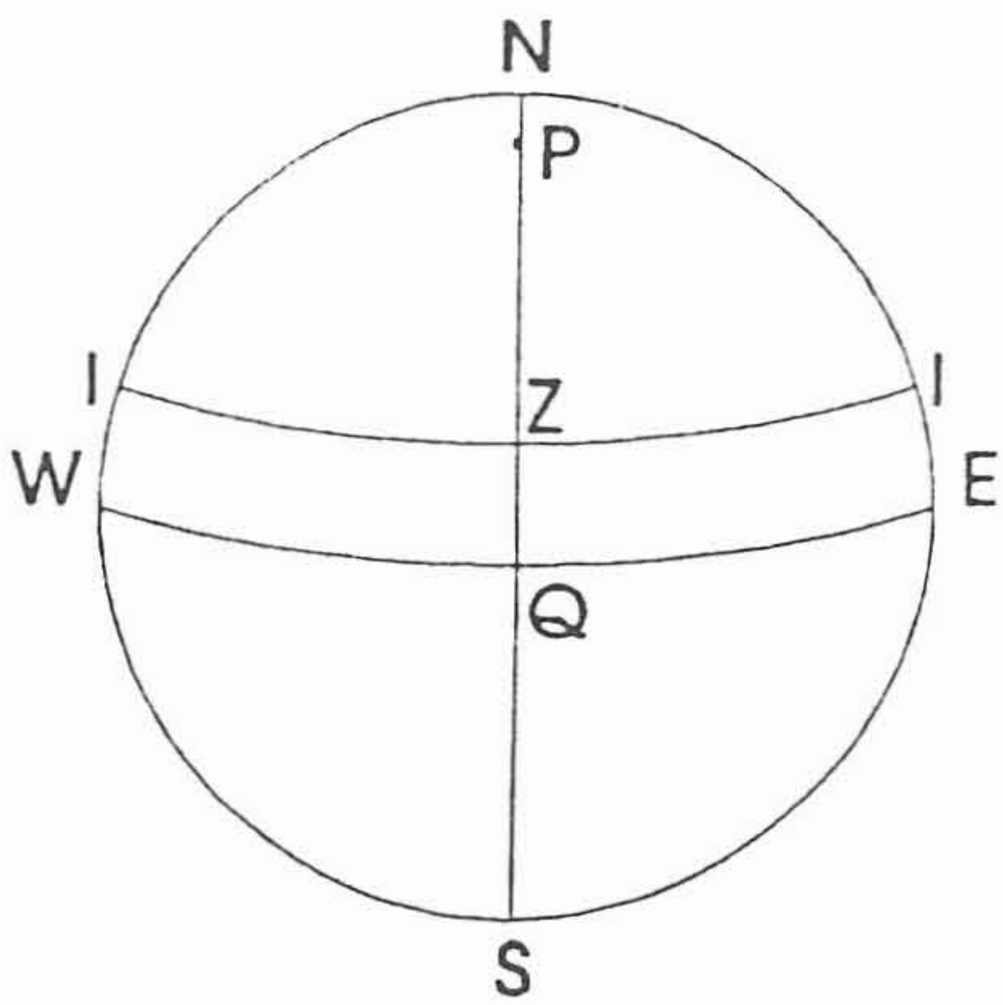


FIGURE B

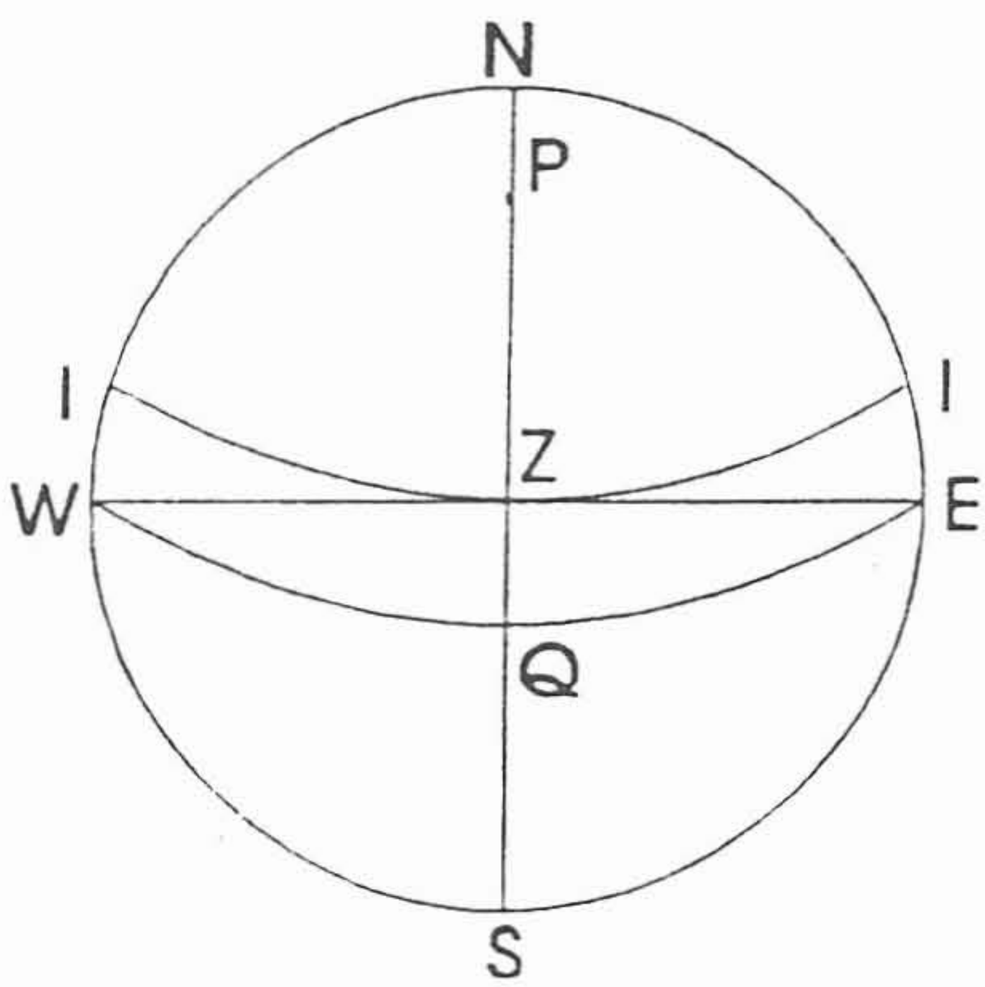
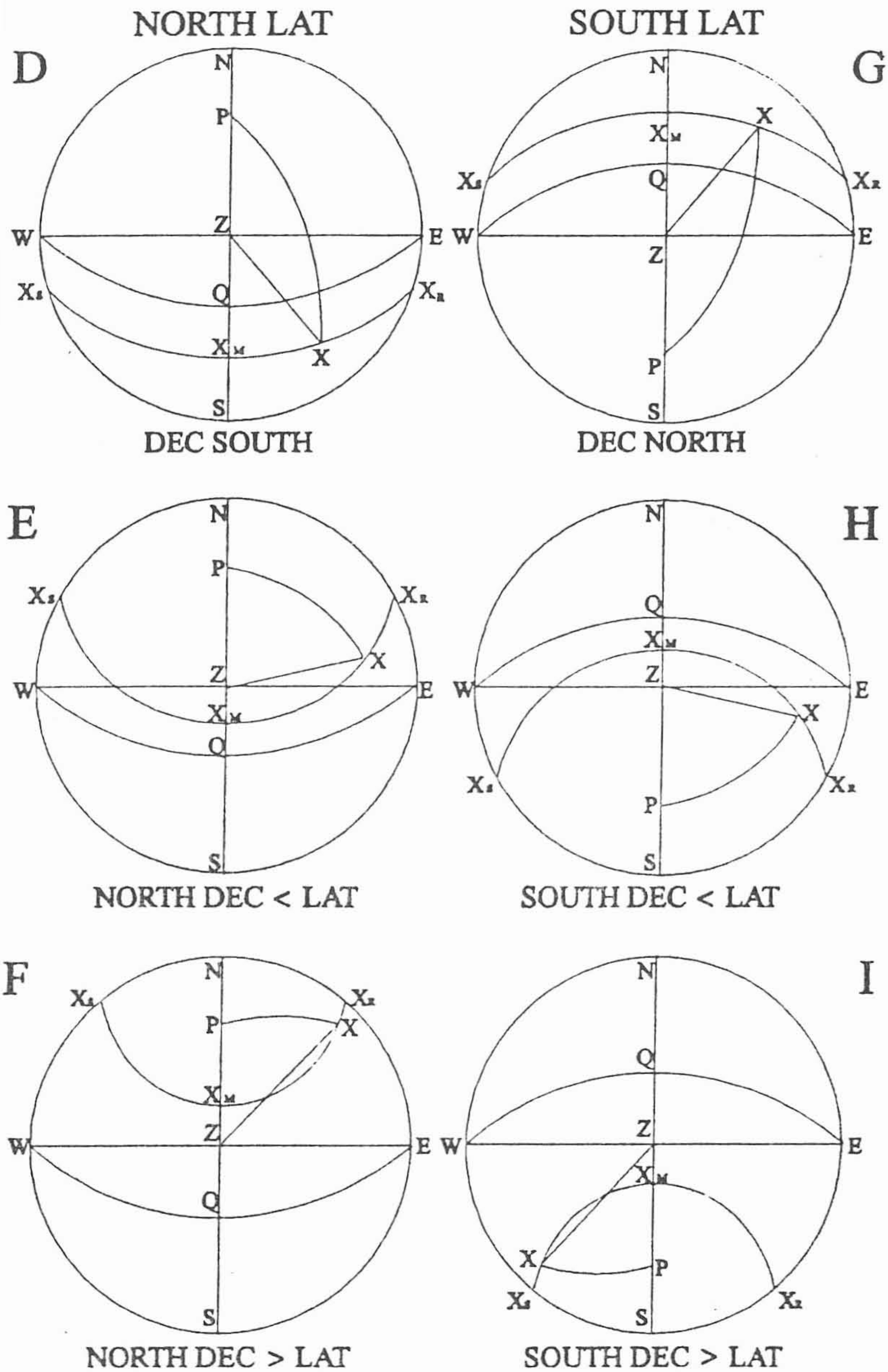


FIGURE C

[3-FIGURE DRAWING]



[3-FIGURE DRAWING]

In figure C, NZ = PQ (each = 90°)

But NZ = NP + PZ and PQ = PZ + ZQ

So NP + PZ = PZ + ZQ

Subtracting PZ from both sides,

NP = ZQ (and each = latitude).

In figure C, we notice that Z (on the surface of the globe) is equidistant from all parts of the circle NESW. Z is hence the pole of the great circle NESW. If the globe now represents the celestial sphere, and Z, the observer's zenith, NESW is called the Rational Horizon of the observer.

Figure C can now be explained as under:

NESW	-	rational horizon or RH
P	-	celestial pole
Z	-	zenith of observer
PZS	-	part of observer's meridian
NP	-	part of observer's inferior meridian
NP -		lat of observer = ZQ
WZE	-	prime vertical circle
NZS	-	principal vertical circle.

NOTE: Any great circle on the celestial sphere, passing through the Zenith of the observer, is called a vertical circle. The N-S vertical circle is called the principal vertical circle and the E-W one, the prime vertical circle.

ll, the parallel of latitude of the observer, was necessary for the explanation of the figure but may now be omitted.

[3-FIGURE DRAWING]

In case the observer is in the southern hemisphere, the globe would be tilted with the north end going away from us, as shown in figures G, H and I.

The position of a celestial body can be inserted in the figure knowing its declination and LHA.

The declination circle of the body can be drawn knowing that it would be a circle, around the pole, with a radius equal to its polar distance (PD).

If the observer's lat was N, we would be considering the north pole. If dec was N, PD = 90 - dec. If dec was S, PD = 90 + dec.

If the observer's lat was S, we would be considering the south pole. If dec was S, PD = 90 - dec. If dec was N, PD = 90 + dec.

NOTE: The Polar Distance of the equinoctial is 90°.

Having drawn the declination circle, the position of the body can be inserted knowing its LHA at that time. When rising, the celestial body would be on the rational horizon east of Z. When setting, it would be on the RH west of Z. When at maximum altitude, the body would be on the meridian (PZQS in figure C).

Various possibilities of latitude and declination are shown in figures D, E, F, G, H and I, wherein the suffix R indicates the point of rising, M indicates the point of meridian passage and suffix S, the point of setting.

4

PRELIMINARY CALCULATIONS

4.1 To obtain d'lat between two given latitudes:

If the latitudes are of the SAME name, SUBTRACT, as illustrated below.

If the latitudes are of DIFFERENT names, ADD, as illustrated below.

	(a)	(b)	(c)	(d)
From	21° 18'N	36° 44'S	43° 27'N	32° 09'S
To	45° 10'N	10° 27'S	12° 30'S	30° 01'N
D'lat	23° 52'N	26° 17'N	55° 57'S	62° 10'N

The name of the d'lat is obtained by comparing the departure and arrival positions -

If going from N lat to more N lat:- d'lat N.
OR from S lat to less S lat:- d'lat N.
OR from S lat to N lat:- d'lat N.

If going from S lat to more S lat:- d'lat S.
OR from N lat to less N lat:- d'lat S.
OR from N lat to S lat:- d'lat S.

4.2 To obtain the m'lat between two places:

If the latitudes are of the SAME name, add, divide by two and retain the name. If the latitudes are of DIFFERENT names, subtract, divide by two and retain the name of the larger one, as illustrated below :-

	(a)	(b)	(c)	(d)
Lat A	10° 26'N	46° 52'S	20° 19'N	37° 48'S
Lat B	30° 50'N	30° 10'S	40° 29'S	53° 36'N
M'lat	20° 38'N	38° 31'S	10° 05'S	07° 54'N

4.3 To obtain d'long between two longitudes:

If the longitudes are of the SAME name, SUBTRACT, as illustrated below.
If the longitudes are of DIFFERENT names, ADD, as illustrated below.

	(a)	(b)	(c)	(d)
From	75° 10'E	124° 11'W	13° 06'E	175° 30'E
To	69° 08'E	136° 14'W	05° 33'W	170° 20'W
D'long	06° 02'W	12° 03'W	18° 39'W	345° 50'W*
				i.e. 14° 10'E

The name of the d'long is obtained by comparing the departure and arrival positions -

If going from E long to more E long:- d'long E.
OR from W long to less W long:- d'long E.
OR from W long to E long:- d'long E.

If going from W long to more W long:- d'long W.
OR from E long to less E long:- d'long W.
OR from E long to W long:- d'long W.

*Where it is necessary to add, and the d'long so obtained is greater than 180°, first put down the value of d'long as it is and name it as above. Then subtract it from 360° and CHANGE THE NAME. This is because d'long can never be greater than 180°.

4.4 Connection between GHA, LHA and long:

Where any two of the above are known, the third can be found by the slogan :-

Longitude **EAST**, GHA **LEAST**
Longitude **WEST**, GHA **BEST**.

i.e., GHA + ~~W~~ E long = LHA and GHA - E long = LHA.

Example A: Given GHA & long, to find LHA:

	(a)	(b)	(c)	(d)
GHA	049° 11.6'	097° 14.8'	343° 18.7'	012° 13.7'
Long	36° 10.0E	20° 40.0W	36° 20.0E	48° 56.0W
LHA	085° 21.6'	076° 34.8'	379° 38.7*	323° 17.7@
			i.e. 019° 38.7'	

* Since LHA cannot be greater than 360°, subtract 360° and the balance is the answer.
@ Where direct subtraction is not possible, add 360° to GHA and then subtract.

Example B: Given LHA & long, to find GHA:

	(a)	(b)	(c)	(d)
LHA	076° 18.2'	227° 17.9'	341° 33.8'	013° 17.6'
Long	30° 11.0E	50° 49.0W	63° 10.0W	48° 04.0E
GHA	046° 07.2'	278° 06.9'	404° 43.8*	325° 13.6@
			i.e. 044° 43.8'	

* Since GHA cannot be greater than 360°. subtract 360° and the balance is the answer.

@ Where direct subtraction is not possible, add 360° to LHA and then subtract.

Example C: Given GHA & LHA, to find long:

Subtract the smaller one from the larger one and name the longitude according to the slogan longitude East GHA least, longitude west GHA best. In NO case must GHA and LHA be added.

	(a)	(b)	(c)	(d)
GHA	087° 11.4'	320° 47.2'	012° 18.3'	327° 18.3'
LHA	110° 19.7'	290° 17.3'	341° 52.5'	040° 32.8'
Long	23° 08.3E	30° 29.9W	329° 34.2E	286° 45.5W
			i.e. 30° 25.8W	073° 14.5E

Where the longitude obtained by direct subtraction is greater than 180°, put it down as it is and name it. Then subtract it from 360° and CHANGE THE NAME. This is because longitude can never be greater than 180°.

4.5 Connection between GMT, LMT & LIT:

When any two of the above are known, the third can be found by applying the slogan -

Long **East** GMT **least**, Long **west** GMT **best**.

i.e., GMT + E long = LMT and GMT - W long = LMT

Example A: Given GMT & long, to find LMT:

	(a)	(b)	(c)	(d)
	d h m s	d h m s	d h m s	d h m s
GMT	18 04 10 06	05 23 40 04	30 20 04 19	12 04 18 12
LIT	E 06 18 36	E 05 00 56	W 08 05 42	W 06 12 36
LMT	18 10 28 42	06 04 41 00	30 11 58 37	11 22 05 36

Example B: Given LMT & long, to find GMT:

	(a)	(b)	(c)	(d)
	d h m s	d h m s	d h m s	d h m s
LMT	21 16 22 10	14 06 12 19	30 05 09 50	19 16 44 10
LIT	E 10 12 16	E 08 09 12	W 05 04 16	W 07 36 04
GMT	21 06 09 54	13 22 03 07	30 10 14 06	20 00 20 14

Example C: Given GMT & LMT, to find long:

Subtract the smaller one from the larger one and name it as per slogan. In NO case should GMT and LMT be added.

	(a)	(b)	(c)	(d)
	d h m s	d h m s	d h m s	d h m s
GMT	18 16 10 30	28 04 10 26	06 08 27 12	19 20 57 16
LMT	18 10 07 50	27 18 27 40	06 11 15 06	20 08 04 08
LIT	06 02 40	09 42 46	02 47 54	11 06 52
long	90° 40'W	145° 41.5W	41° 58.5'E	166° 43'E

4.6 SHA of stars:

Find the GHA and dec of SIRIUS at 18h 24m 10s on Jan 20th 92.

Referring to page of 20th Jan in Almanac:

GHA γ 20d 18h	029° 22.6'
Incr 24m 10s	6° 03.5'
GHA γ for GMT	035° 26.1'
SHA ★ SIRIUS	258° 47.4'
GHA ★ SIRIUS for GMT	294° 13.5'
Dec ★ SIRIUS for 20d	16° 42.4'S

-o0o-

5

PLANE AND PARALLEL SAILING

THE PLANE SAILING TRIANGLE:

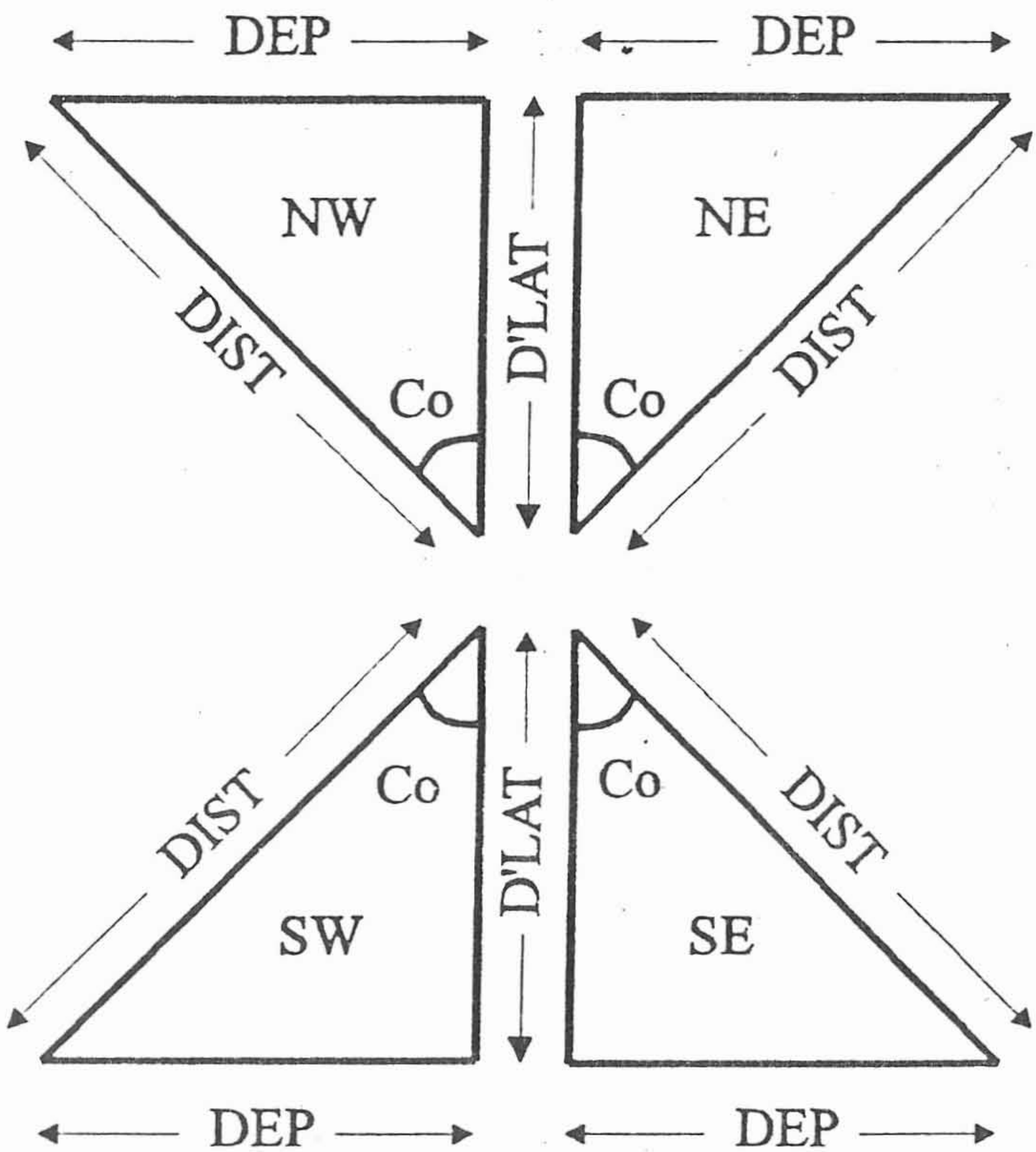
Small portions of the earth may be considered to be a flat or plane surface without appreciable error. Where the distance between two places is less than 600 miles or so, plane trigonometry can be used to :-

(a) compute the course the distance between two positions
(b) calculate the position arrived given the starting position, course and distance steamed.

To facilitate easy calculation, ready solutions of right angled triangles are available in the form of Traverse Tables. The use of Traverse Tables is illustrated in Chapter 6 of this book.

In order to obtain a plane sailing triangle, the course is first converted from three figure notation into quadrantal notation (NE, SE, SW and NW). The actual distance between two places is split up into its N-S component and its E-W component, as illustrated below. In each case, the plane sailing triangle will be similar to one of the four triangles shown below, depending on the quadrantal course - NE, SE, SW or NW.

The N-S component is the d'lat between the two places and the E-W component, the departure (dep). All the three sides - dist, d'lat and dep - are expressed in M (nautical miles). One M = 1852 m or 1.852 km. Also one km = 0.54 M.



THE PARALLEL SAILING FORMULA:

To convert the dep into d'long, or vice versa, the parallel sailing formula is used:

$$\frac{\text{Dep}}{\text{D'long}} = \text{Cos m'lat}$$

Note: Technically speaking, the right side of the above formula should read mid lat instead of mean lat. The application of a very small correction to mean lat would convert it into mid lat. This is because the earth is an oblate spheroid and not a perfect sphere. In practical navigation, for the sake of convenience, mean lat is used instead of mid lat as the resultant error is insignificant.

5.1 To find the position arrived, given the starting position, course and distance:

Worked example

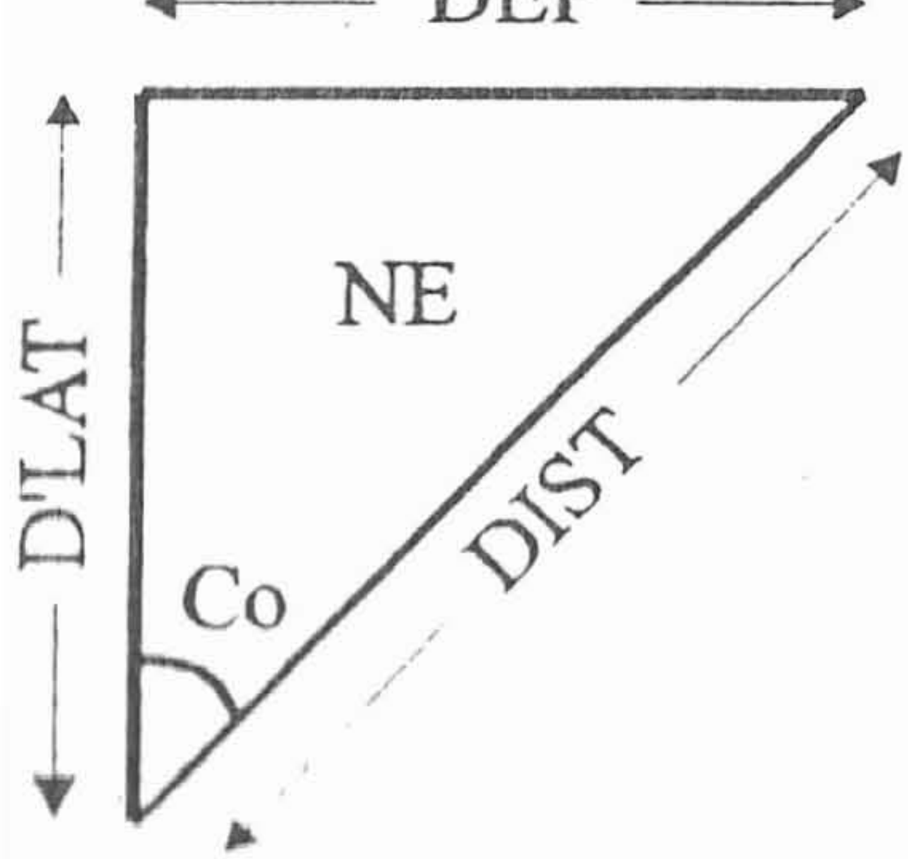
Given the starting position to be 20° 11'N 72° 52'W, course 032°(T) and distance 238 M, find the position arrived.

032°(T) = N32°E. Dist = 238 M.

d'lat = dist.Cos co = 238.Cos 32°

Log 238	2.37658	lat left	20° 11.0'N
Log Cos 32°	-1+0.92842	d'lat	3° 21.8'N
Log d'lat	2.30500	lat arr'd	23° 32.8'N
d'lat = 201.84' =	3° 21.8'N	m'lat	21° 52'

Dep = dist . Sin Co = 238 . Sin 32°



Log 238	2.37658
Log Sin 32°	-1+0.72421
Log dep	2.10079

dep = 126.12'E

d'long = dep . Sec m'lat
= 126.12.Sec 21°52'

Log 126.12	2.10079
Log Sec 21°52'	0.03243
Log d'long	2.13322

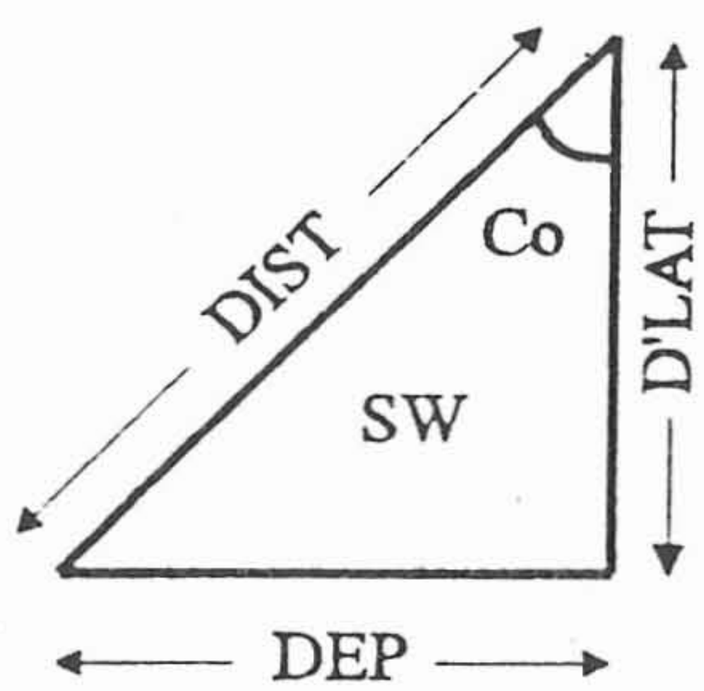
d'long	=	135.9'E	=	02° 15.9'E
long left				72° 52.0'W
long arr'd				70° 36.1'W

Pos arrived: 23° 32.8'N 70° 36.1'W **Answer.**

5.2 To find the course and distance between two positions:

Worked example

Find Co & Dist from 20° 10'N 179° 40'W to 13° 40'N 178° 10'E.



From: lat 20° 10'N long 179° 40'W
To : lat 13° 40'N long 178° 10'E
d'lat 6° 30'S d'long 357° 50'E

i.e., 2° 10'W

d'lat =390'S, d'long = 130'W, and

m'lat 16°55'

dep = d'long . Cos m'lat
= 130 . Cos 16° 55'

Log 130	2.11394
Log Cos 16° 55'	-1+0.98079
Log dep	2.09473
dep	124.38'E

Tan Co = dep / d'lat = 124.38 / 390

Log 124.38	2.09473
Log 390	2.59106
Log Tan Co	-1+0.50367

Course S 17° 41'W **Answer (i).**

dist = d'lat . Sec Co = 390 . Sec 17° 41'

Log 390	2.59106
Log Sec 17° 41'	0.02102
Log dist	2.61208

Distance = 409.34 M **Answer (ii).**

5.3 To find the set and drift of current:

Set and drift of current is the course and distance FROM the DR position TO the fix. Drift is expressed in miles. Where required, the rate of current can be obtained in knots by dividing the drift by the number of hours during which the drift occurred. The working is similar to that explained earlier in 5.2. Hence no worked example is shown here separately.

EXERCISE 1

(Plane & parallel sailing)

In the following cases, find the position arrived:

	STARTING POSITION			
	Latitude	Longitude	Course	Distance
1	10° 20'N	060° 20'E	155°	300 M
2	10° 12'S	120° 11'W	260°	458 M
3	00° 10'S	179° 40'W	340°	510 M
4	60° 11.2'N	120° 18.6'E	250°	312.4 M
5	30° 14'S	168° 12'W	046°12'	426.8 M

In the following cases, find the course and distance:

	FROM		TO	
	Latitude	Longitude	Latitude	Longitude
6	20° 30.0'N	179° 36.0'E	16° 18.0'N	178° 32.0'W
7	03° 12.0'N	004° 11.3'E	02° 30.4'S	002° 10.0'W
8	56° 12.5'S	046° 12.5'W	50° 11.3'S	044° 14.8'W
9	36° 11.7'N	075° 12.6'E	40° 18.6'N	080° 11.5'E
10	60° 11.6'N	076° 44.3'W	55° 10.3'N	080° 16.8'W

In the following cases, find the set and drift of current:

	DR		FIX	
	Latitude	Longitude	Latitude	Longitude
11	46° 44.3'N	076° 36.3'E	47° 00.6'N	076° 10.4'E
12	30° 16.8'S	057° 49.3'E	31° 00.7'S	058° 20.4'E
13	00° 11.6'N	179° 50.2'W	00° 40.3'S	178° 40.1'E
14	60° 20.6'S	176° 18.4'W	60° 01.7'S	175° 54.9'W
15	50° 16.3'N	000° 12.3'E	49° 50.4'N	000° 20.1'W

6

THE USE OF

TRAVERSE TABLES

Traverse Tables are ready solutions of right angled triangles to facilitate navigational calculations. In this chapter, the illustrations are limited to the solution of problems in plane and parallel sailing.

6.1 To find the position arrived given the starting position, course and distance:

Worked example 1

Starting position 20° 11'N 72° 52'W, Co 032° (T) dist 238 M. To find the position arrived.

(1) Convert the three figure notation into a quadrantal one - 032° becomes N32°E.

(2) If the quadrantal Co is less than 45°, **enter** TT **from** the **top** and use the column headings from the top of the page, as shown in **capital** letters, in the following diagram:-

If the quadrantal Co is **more** than 45°, **enter** TT **from** **below** and use the column headings from bottom of the page, as shown in **capital** letters, in the following diagram:-

32°

D'LONG	*DEP*	
DIST	D'LAT	DEP

DIST	DEP	D'LAT
D'LONG		*DEP*

58°

(3) From TT, for Co = 32° and dist = 238 M, extract values of d'lat and dep. Since Co is N32°E, d'lat must be N and dep must be E. Values are d'lat = 201.8'N and dep = 126.1'E.

(4) Apply d'lat to the departure latitude and obtain the latitude arrived.

(5) Obtain the m'lat (to the nearest decimal of a degree) between the departure and arrival latitudes. In this case, m'lat = 21.9°.

(6) Enter TT again, using m'lat in place of course.

If m'lat is less than 45°, enter TT from the top of the page and use the columns shown in italics in the foregoing figure.

If m'lat is more than 45°, enter TT from bottom of the page and use the columns shown in italics in the foregoing figure.

(7) Locate 126.1 in the dep column and obtain d'long from its column, interpolating as necessary. D'long will always have the same name as dep.

In this case, interpolation is as follows:

m'lat 21°, dep 126.1, d'long = 135.1'
m'lat 22°, dep 126.1, d'long = 136.0'
m'lat 1° changes d'long by 0.9'
so 0.1° changes d'long by 0.1'

For m'lat 21.9° dep 126.1, d'long = 135.9'
i.e., d'long = 2° 15.9'E

(8) Apply d'long to the longitude left and obtain the longitude arrived.

Method of showing written work:

Left lat	20°	11.0'N	long	72°	52.0'W	Co N32E	238 M
d'lat	3°	21.8'N	d'long	2°	15.9'E	dep = 126.1'E	
Arrd lat	23°	32.8'N	long	70°	36.1'W	m'lat = 21.9°N	

Worked example 2

From position 36° 18'S 178° 46'W, a course of 294° (T) was steamed for 177 M. Find the position arrived.

294° = N66°W. Since Co > 45°, enter TT from below.

Left lat	36°	18.0'S	long	178°	46.0'W	Co N66W	177 M
d'lat	1°	12.0'N	d'long	3°	19.1'W	dep = 161.7'W	
Arrd lat	35°	06.0'S	long	182°	05.1'W	m'lat = 35.7°S	
			i.e.,	177°	54.9'E		

Note: Since the long. arrived exceeds 180°, subtract it from 360° and change its name, as explained in Chapter 4.

Worked example 3

From a position 00° 10'N 178° 57'E, a course of 156° 18' (T) and a distance of 321.3 M were made good. Find the position arrived.

Co 156° 18' = S23° 42'E = S23.7°E

From TT:	Co S23°E	dist 321.3'	d'lat 295.8'S	dep 125.5'E
	Co S24°E	dist 321.3'	d'lat 293.5'S	dep 130.7'E

Interpolating between Co 23° & Co 24° for 23.7°, d'lat = 294.2'S.
Interpolating between Co 23° & Co 24° for 23.7°, dep = 129.1'E.

Method of showing written work:

Left	lat 00° 10.0'N	long 178° 57.0'E	S23.7°E	321.3 M	
	d'lat 04° 54.2'S	d'long 002° 09.2'E	dep = 129.1'E		
Arrd	lat 04° 44.2'S	long 181° 06.2'E	m'lat = 2.3°S		
		i.e., 178° 53.8'W			

6.2 To find the course & distance between two given positions

(1) Write down the two given positions and obtain the d'lat and d'long between them. Name them FROM the position left TO the position arrived.

(2) Calculate the m'lat to the nearest decimal of a degree.

(3) Enter TT using the m'lat & d'long and obtain the dep.

If the **m'lat** is **less** than 45°, **enter** TT from the **top** and use the column **headings** from the **top** of the page as shown here in **italics**:-

If the **m'lat** is **more** than 45°, **enter** TT from **below** and use the column **headings** from **bottom** of the page as shown here in **italics**:-

32°

D'LONG	*DEP*	
DIST	D'LAT	DEP

DIST	DEP	D'LAT
D'LONG		*DEP*

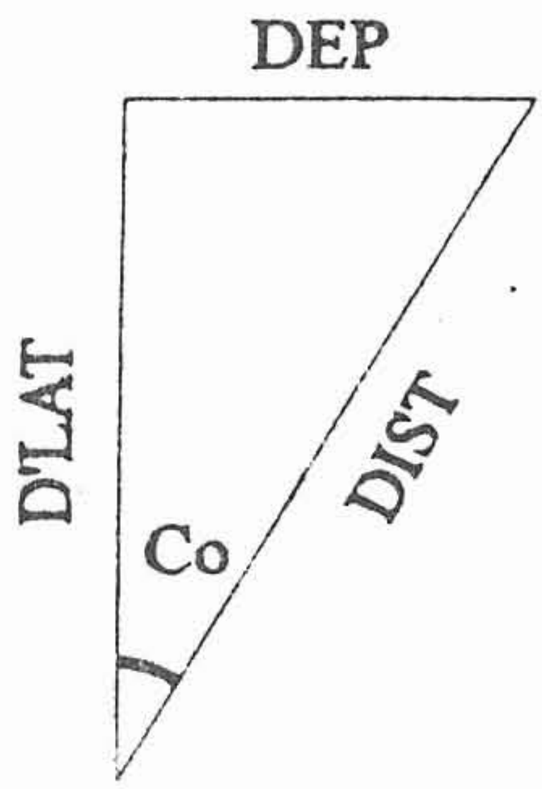
58°

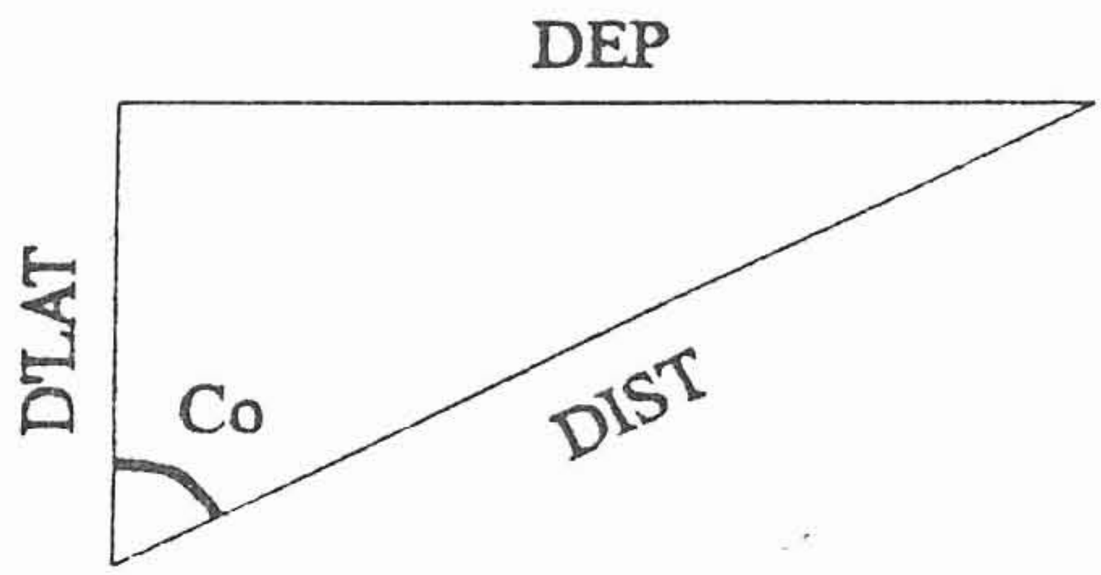
(4) Compare the d'lat and dep as follows:

(a) If d'lat & dep are equal, course = 45°. So if they are nearly equal, course must be near about 45°. If they differ by a large amount, course will be far away from 45° (closer to 0 or 90°)

(b) If d'lat is more than dep, Co must be less than 45° (as illustrated below) so enter TT from above using capital letter headings:

If dep is more than d'lat, Co must be more than 45° (as illustrated below) so enter TT from below using capital letter headings:





(5) Bearing in mind the foregoing points, enter TT using the capital letter columns shown in the figure and locate the page having the values of d'lat and dep closest to the required values. Interpolate for the Co and dist as shown in the following worked example:-

Worked example

Find the course & distance from 20° 10'N 179° 40'W to 13° 40'N 178° 10'E.

From	lat	20° 10'N	long	179° 40'W
To	lat	13° 40'N	long	178° 10'E
	d'lat	06° 30'S	d'long	357° 50'E
			i.e.,	2° 10'W

d'lat = 390'S d'long = 130'W m'lat = 16.9°N

From TT, m'lat 16.9° and d'long 130'W, dep = 124.4'W

Bearing in mind the points mentioned in 6.2 (4):

Step number 1:-
To obtain Co from TT:

Co	d'lat	dep
??	390.0	124.4
18°	390.0	126.7
17°	390.0	119.2
60'	changes	7.5
18'	←←←	2.3
17.7°	390.0	124.4

Course = S17° 42' W

Step number 2:-
To get dist from TT:

Co	d'lat	dist
17.7°	390.0	??
18°	390.0	410.1
17°	390.0	407.8
60'	changes	2.3
18'	→→→	0.7
17.7°	390.0	409.4

Distance = 409.4M

6.3 To calculate the set and drift of current:

Set and drift of current is the course and distance FROM the DR position TO the Fix. The working is similar to that explained in 6.2 but the interpolation may be simpler, because of the small distance involved, as illustrated below:-

Worked example

At 0800 hours the DR position of a ship being 10° 12.5'S 47° 42'W, a fix was obtained and found to be 10° 04.3'S 47° 56.6'W. Find the set and drift of current.

DR lat	10°	12.5'S	long	47°	42.0'W	m'lat	10.1°S
Fix lat	10°	04.3'S	long	47°	56.6'W		
D'lat		08.2'N	d'long		14.6'W		

m'lat	d'long	dep
10.1°	14.6	??

NOTE: By using 146 instead of 14.6 to enter TT, interpolation is much faster. The decimal point in the dep so obtained can be inserted later.

m'lat	d'long	dep
10°	146	143.8
11°	146	143.3
10.1°	146	143.8
10.1°	14.6	14.4

So d'lat = 8.2'N and dep = 14.4'W

Step number 1:-
To obtain Co from TT:

Co	dep	d'lat
??	14.4	8.2

Step number 2:-
To get dist from TT:

Co	dep	dist
60.3°	14.4	??

NOTE: By using 144 & 82 instead of 14.4 & 8.2 to enter TT, interpolation is much faster. The decimal points can be inserted after interpolation.

Step number 1:-
To obtain Co from TT:

Co	dep	d'lat
60°	144	83
61°	144	80
60'	changes	3
20'	←←←	1
60.3°	144	82
60.3°	14.4	8.2

Course (set) = N60° 20' W

Step number 2:-
To get dist from TT:

Co	dep	dist
60°	144	166
61°	144	165
60'	changes	1
20'	→→→	0.3
60.3°	144	165.7
60.3°	14.4	16.6

Dist (drift) = 16.6M

Note: The above interpolation has been written elaborately in order to explain the method to the student. The actual interpolation can be done mentally very quickly and the answer written down.

-o0o-

EXERCISE 2

(Use of Traverse Tables)

Using ONLY Traverse Tables, find the position arrived:

	STARTING POSITION			
	Latitude	Longitude	Course	Distance
1	10° 20'N	060° 20'E	155°	300 M
2	10° 12'S	120° 11'W	260°	458 M
3	00° 10'S	179° 40'W	340°	510 M
4	60° 11.2'N	120° 18.6'E	250°	312.4 M
5	30° 14'S	168° 12'W	046°12'	426.8 M

Using ONLY Traverse Tables, find the course and distance:

	FROM		TO	
	Latitude	Longitude	Latitude	Longitude
6	20° 30.0'N	179° 36.0'E	16° 18.0'N	178° 32.0'W
7	03° 12.0'N	004° 11.3'E	02° 30.4'S	002° 10.0'W
8	56° 12.5'S	046° 12.5'W	50° 11.3'S	044° 14.8'W
9	36° 11.7'N	075° 12.6'E	40° 18.6'N	080° 11.5'E
10	60° 11.6'N	076° 44.3'W	55° 10.3'N	080° 16.8'W

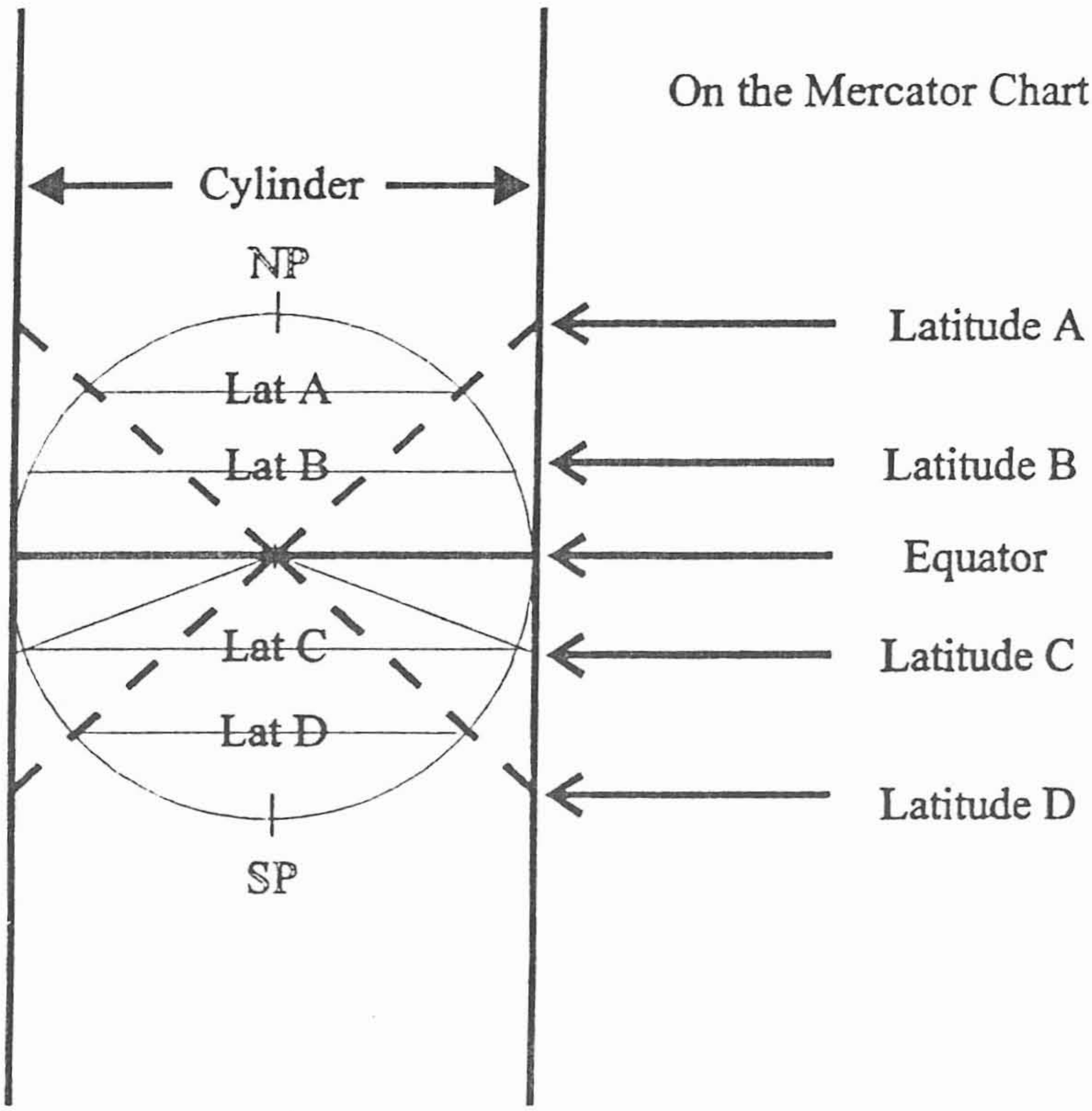
Using ONLY Traverse Tables, find the set & drift of current:

	DR		FIX	
	Latitude	Longitude	Latitude	Longitude
11	46° 44.3'N	076° 36.3'E	47° 00.6'N	076° 10.4'E
12	30° 16.8'S	057° 49.3'E	31° 00.7'S	058° 20.4'E
13	00° 11.6'N	179° 50.2'W	00° 40.3'S	178° 40.1'E
14	60° 20.6'S	176° 18.4'W	60° 01.7'S	175° 54.9'W
15	50° 16.3'N	000° 12.3'E	49° 50.4'N	000° 20.1'W

7

THE MERCATOR CHART

The three dimensional, curved surface of the earth has to be represented on a two dimensional flat surface of a chart for the sake of convenience in navigation. Mercator solved this problem by using the cylindrical projection. Imagine that the earth is a transparent globe with parallels of latitude and meridians of longitude drawn on it. Imagine that a cylinder, having the same radius as that of the globe, is placed enclosing the globe, tangential to the equator. Imagine that a source of light is placed at the centre of the globe and the projections of the parallels of latitude and meridians of longitude on the inside of the cylinder get marked permanently. If the cylinder is now cut along its length, opened out and placed on a flat table, it would represent a Mercator Chart wherein the following characteristics will be apparent:-



(a) The equator appears as a straight line.

(b) All meridians appear as straight lines parallel to, and equidistant from, each other and cross the equator at right angles.

(c) Parallels of latitude would appear as straight lines parallel to each other but the distance between consecutive parallels would increase as latitude increases.

(d) Polar regions do not appear.

(e) One minute of d'long is the same size in all parts of the chart (as mentioned in (b) above).

(f) One minute of d'lat increases in size steadily as we go away from the equator (as mentioned in (c) above).

Distances

On a Mercator chart the distance, in any direction, measured in minutes of latitude is the distance in Nautical Miles.

Note: Since the size of one minute of latitude on a Mercator chart increases as latitude increases, the dividers should be used against the latitude in which the distance lies. For example, if place A is in latitude 24°N, and place B is in latitude 26°N, one leg of the dividers should be placed on A, the other on B and that represents the distance AB on that chart. To read off the value of the distance, the dividers should be placed N-S along the latitude markings on the chart such that the centre of the dividers lies on latitude 25°N and then the d'lat contained between the legs read off in minutes. Suppose the d'lat so obtained is 180', the distance AB is 180 Nautical Miles.

Dep and d'long

On a Mercator chart, the E-W distance between two places, measured along the latitude scale (in minutes of latitude), is the departure between them in Nautical Miles but, if measured along the longitude scale (in minutes of longitude), it is the d'long between them.

D'lat and DMP

On a Mercator chart, the N-S distance between two places, measured along the latitude scale, is the d'lat between them (in minutes or Nautical Miles) but, if measured along the longitude

scale (in minutes of LONGITUDE), it is called the DMP (difference of meridional parts) between them.

MERIDIONAL PARTS

Meridional Parts for any latitude is the arc of the meridian, or the angle at the centre of the earth, contained between the equator and that parallel of latitude, expressed in minutes of LONGITUDE. In other words, the N-S distance from the equator to any parallel of latitude, expressed in minutes of LONGITUDE, is called the Meridional Parts (MP) for that latitude. MP for each latitude is given in Nautical Tables.

DMP

Difference of Meridional Parts or DMP between any two parallels of latitude is the arc of the meridian, or the angle at the centre of the earth, contained between those two parallels of latitude, expressed in minutes of LONGITUDE. In other words, the N-S distance between the two parallels of latitude, expressed in minutes of LONGITUDE, is called the DMP between them.

DMP between position A and position B is the difference between the MP for latitude A and that for latitude B, both of which are extracted from Nautical Tables. The rule, whether to add or subtract, is similar to that for obtaining d'lat between two places - same names subtract, different names add.

RHUMB LINE

A rhumb line is one that cuts all meridians at the same angle. It would appear as a straight line on a Mercator chart but, on the surface of the earth, a rhumb line would be curved. This is because, on a Mercator Chart, meridians appear parallel to each other whereas, on the surface of the earth, they are not.

8

MERCATOR

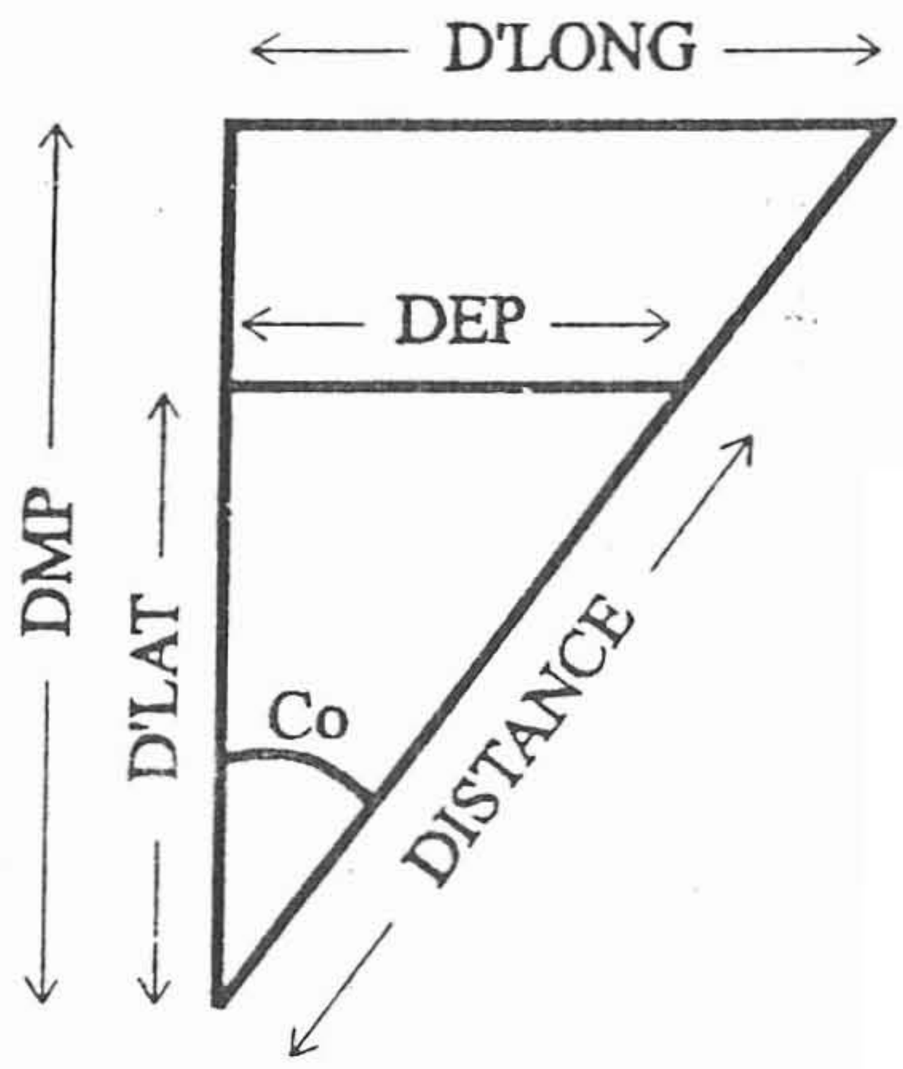
SAILING

Where the distance exceeds 600 M, it is recommended that the calculation be done by Mercator Sailing in order to get more accurate results than by plane and parallel sailing methods.

Mercator Sailing Formula:

$$\frac{\text{D'long}}{\text{DMP}} = \text{Tan Co}$$

For the sake of convenience, the above formula can be superimposed on the plane sailing triangle, as shown here.



Worked example 1

Find the rhumb line course and distance from starting position P 02°12'S 160°18'W to final position Q 10°19'N 140°40'W.

				From Tables	
lat P	02° 12'S	long P	160° 18'W	MP of P	131.1S
lat Q	10° 19'N	long Q	140° 40'W	MP of Q	618.2N
d'lat	12° 31'N	d'long	19° 38'E	DMP	749.3
i.e.,	751'N	i.e.,	1178'E		

Note: To get DMP, apply same rule as for d'lat - same names subtract, different names add.

Tan Co = d'long / DMP = 1178 / 749.3

Course = N57° 32'E **Answer (i).**

Log 1178	3.07115
Log 749.3	2.87466
Log Tan Co	0.19649

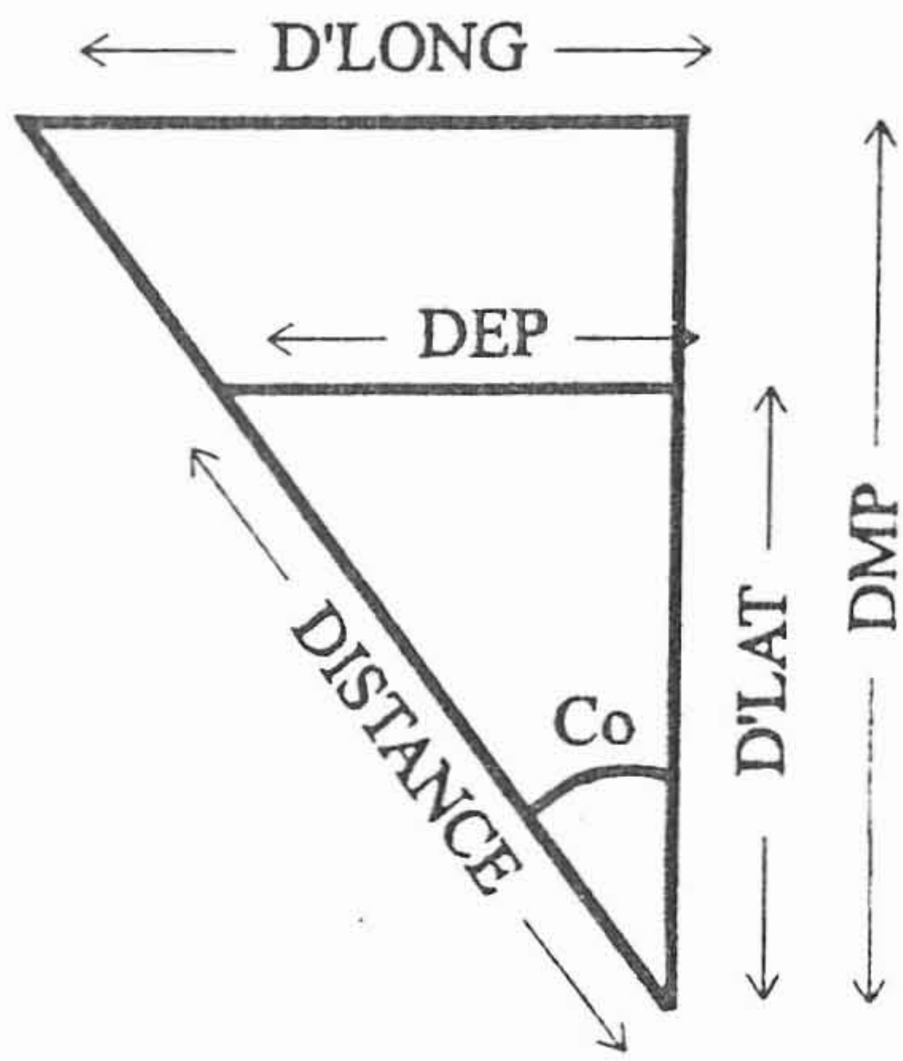
To get distance, use the plane sailing formula:

dist = d'lat . Sec Co
= 751 . Sec 57° 32'
distance = 1399.0 M **Answer (ii).**

Log d'lat	2.87564
Log Sec Co	0.27018
Log dist	3.14582

Worked Example 2

Find by Mercator's Principle, the position arrived if a ship sailed a course of 301° (T) for 1408 M from position 00° 04'S 178° 20'W.



301° = N59°W

d'lat = dist . Cos Co
= 1408 . Cos 59°

Log 1408	3.14860
Log Cos 59°	-1+0.71184
Log d'lat	2.86044

d'lat = 725.16' = 12° 05.2' N

lat left	00° 04.0'S	MP for lat left	4.0 S
d'lat	12° 05.2'N	MP for lat arr'd	721.7 N
lat arr'd	12° 01.2'N	DMP	725.7

$$\frac{\text{d'long}}{\text{DMP}} = \text{Tan Co} \qquad \text{or} \qquad \text{d'long} = \text{DMP . Tan Co}$$

d'long = 752.7 . Tan 59°

Log 725.7	2.86076
Log Tan 59°	0.22123
Log d'long	3.08199

d'long = 1207.8'W

long left	178° 20.0'W
d'long	20° 07.8'W
long arr'd	198° 27.8'W
i.e.,	161° 32.2'E

Pos arrived :- lat 12° 01.2'N long 161° 32.2'E **Answer.**

EXERCISE 3

(Mercator Sailing)

Find, by Mercator Sailing, the course and distance:-

	FROM		TO	
	Latitude	Longitude	Latitude	Longitude
1	24° 00'N	074° 15'W	46° 00'N	053° 45'W
2	06° 00'N	079° 00'W	38° 00'S	179° 00'E
3	40° 18'N	100° 20'W	68° 00'N	140° 10'E
4	70° 20'N	010° 22'W	52° 50'N	009° 45'E
5	32° 29'S	064° 00'E	49° 50'S	005° 15'E

Find, by Mercator's Principle, the position arrived:-

	Starting position			
	Latitude	Longitude	Course	Distance
6	36° 48'N	085° 53'W	241°	1897 M
7	06° 10'S	176° 47'W	333°	4450 M
8	38° 18'S	005° 11'W	124°	3256 M
9	44° 11'N	140° 20'W	056°	2222 M
10	18° 58'N	072° 52'E	265°	7126 M

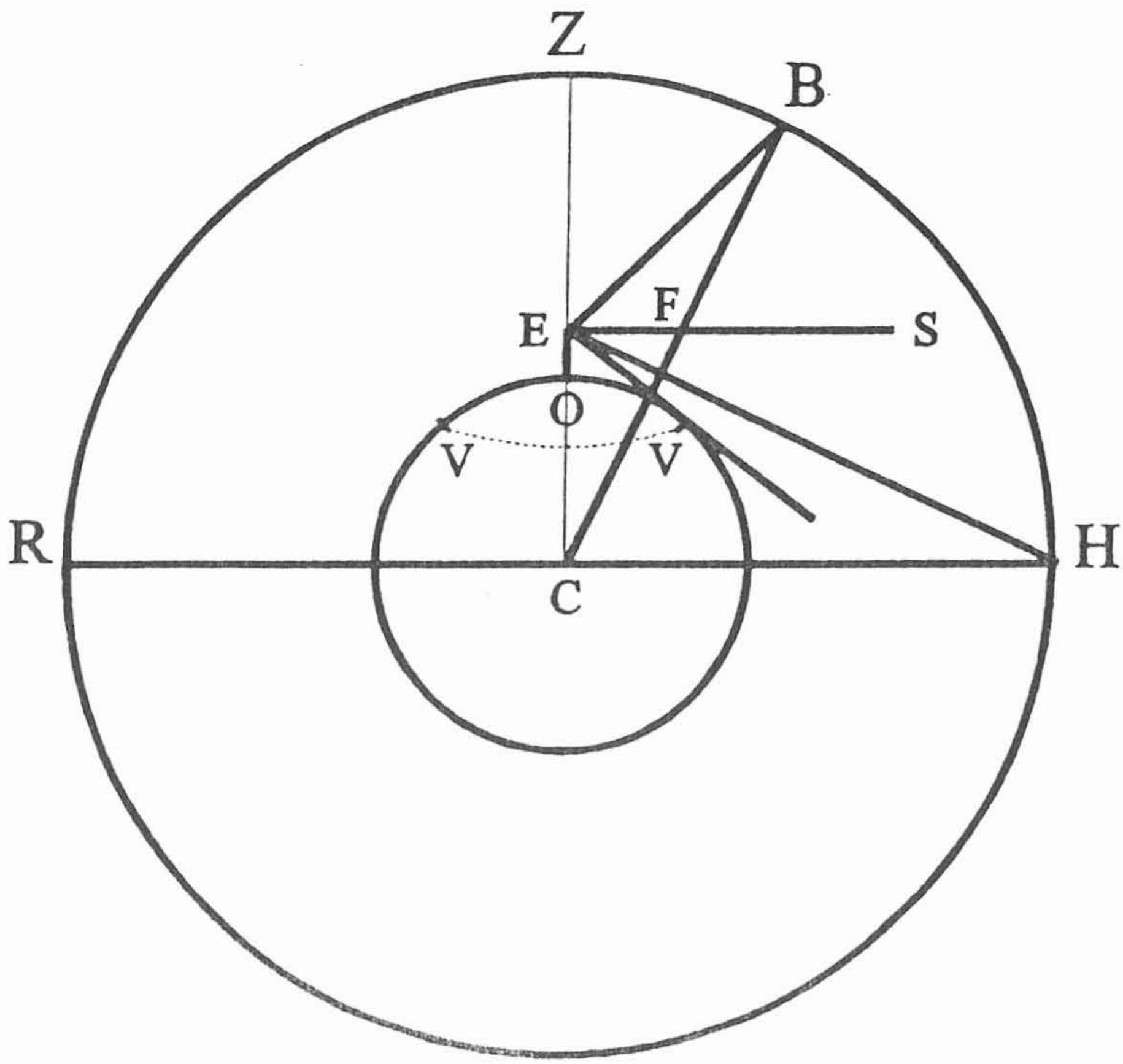
9

CORRECTION OF

ALTITUDES - THEORY

In the following figure,

C is the centre of the earth & also that of the celestial sphere.
B is a celestial body on the celestial sphere.
O is the position of the observer on the earth's surface.
E is the eye of the observer.
OE is the height of the observer's eye above the sea surface. It includes his own height and that of the bridge deck above the sea.
VV is the visible horizon of the observer.
ES is the sensible horizon.
Z is the observer's zenith.
RH is the rational horizon of observer. It is a great circle, of the celestial sphere, of which Z is the pole.
BEV is the observed altitude of the body above the visible horizon.
SEV is the angle of 'dip'. It depends on the height of the observer's eye above the sea surface.



BES is the apparent altitude of the body. It is obvious from the figure that BES = BEV - SEV i.e., App alt = Obs alt - dip.

EBC is the angle of parallax, or parallactic angle, which is the angle subtended at the body by the radius of the earth. OE is negligible compared to CB, CE & EB and is hence diregarded for this purpose. Stars and planets are so far away that the radius of the earth does not subtend a finite angle at that distance. Hence there is no parallax for stars and planets. Parallax is significant for the Sun and the Moon. It will be noticed from the figure that the value of parallax is maximum when the body is on the rational horizon and nil when it at the zenith of the observer. Hence

the correction for parallax is tabulated against apparent altitude.

EHC is the horizontal parallax or the parallax when the body is on the observer's rational horizon.

BCH is the true altitude of the body i.e., the altitude, at the centre of the earth, of the body above the rational horizon. From the figure it is obvious that:

BCH = BFS (because ES is parallel to CH).

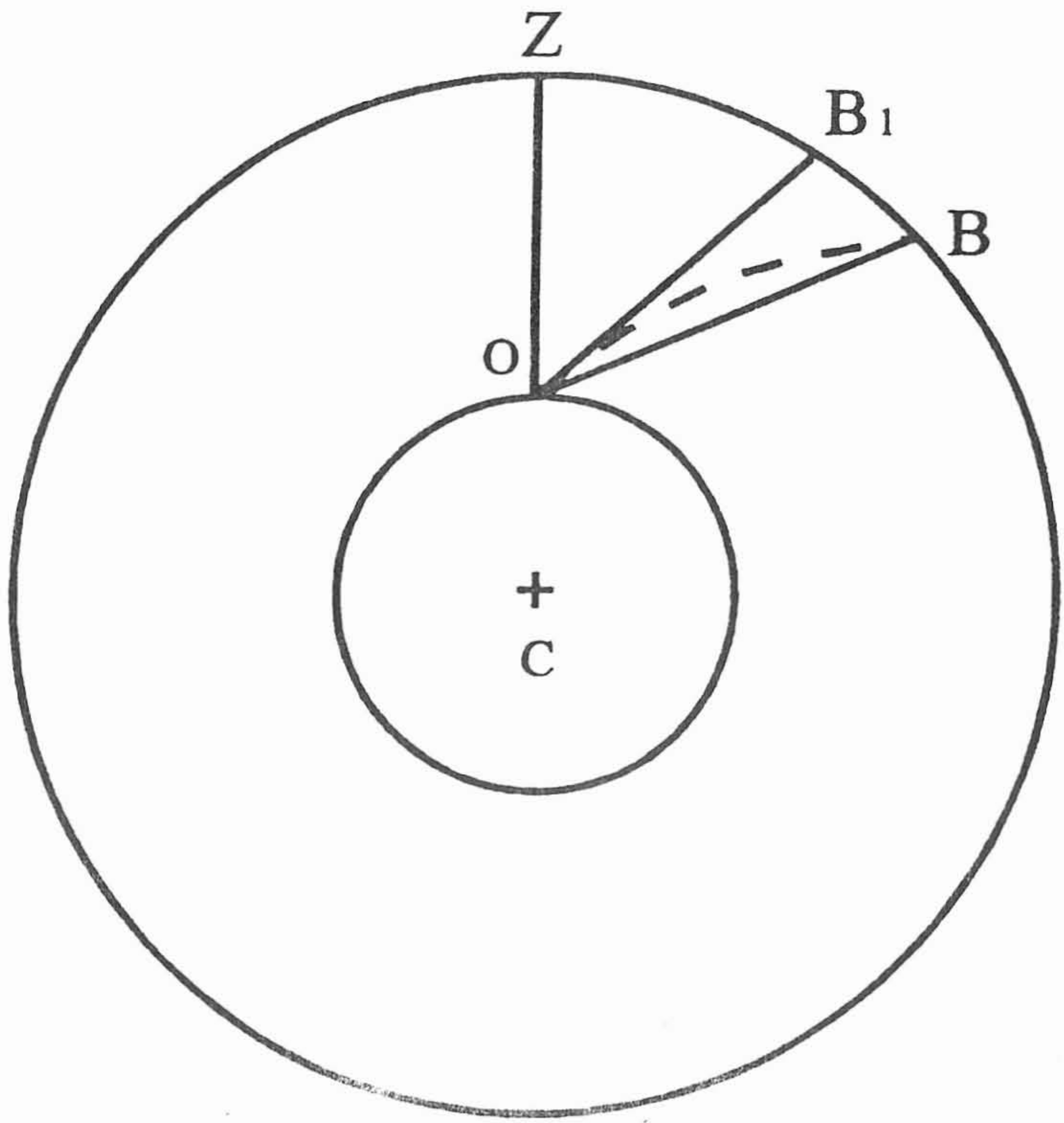
But BFS = BES + EBC
(exterior angle = sum of interior opposite angles).

Hence BCH = BES + EBC, or True alt = App alt + Parallax.

Correction for refraction:

While passing through the atmosphere, the rays of light coming from a celestial body get refracted. Since the density of the air gets less and less as height above the earth's surface increases, refraction causes the body to appear at a higher altitude than the real altitude. Hence the correction for refraction is always negative, as shown in the following figure wherein the body at B appears to be at B_1.

The correction for refraction is maximum when the altitude is nil and gradually decreases in value until it is nil when the body is overhead. This is because, when the altitude is nil or low, the angle of incidence is very high whereby the rays pass obliquely through the atmosphere. When the altitude is 90°, the angle of incidence is nil whereby the rays are normal to the layers of atmosphere. Hence the correction for refraction is tabulated against apparent altitude.



Correction for Semi-diameter:

It is not possible to obtain the altitude of the centre of the Sun or Moon directly with a sextant because they appear as large discs. Hence we observe the altitude of either the lower limb (LL) or the upper limb (UL) and then apply a correction. When the LL is observed, the centre of the disc would be higher than the altitude observed and hence semi-diameter has to be added. Similarly, when observing the UL, the semi-diameter correction is subtractive.

10

CORRECTION OF ALTITUDES - PRACTICAL

10.1 Correction of altitudes of all celestial bodies except the MOON:-

This is illustrated by a worked example with comments where necessary.

On 16th March 1992, the sextant altitude of the Sun's lower limb was 56° 11.4'. If the index error of the sextant was 2.8' off the arc and the height of eye was 12m, find the true altitude.

Sext alt	56° 11.4'	
IE	(+) 2.8'	[Off = (+), On = (-)]
Obs alt	56° 14.2'	
Dip (HE 12m)	(-) 06.1'	[Always (-)]
App alt	56° 08.1'	
Tot. corm	(+) 15.6'	[LL (+), UL (-)]
T alt	56° 23.7'	

NOTES

1: Corrections for altitude may be taken from Nautical Tables or from the Nautical Almanac.

2: Dip is tabulated against height of eye and is always subtracted from Obs alt to get App alt.

3: App alt is obtained in the above manner for all celestial bodies.

4: Total correction (Tot. corrn) is tabulated against App alt.

5: FOR THE SUN, total correction is given in two columns - one for October to March and the other for April to September. Different columns are also given for upper limb (UL) and for lower limb (LL). Total correction should be applied according to the sign given therein. However, it will be observed that total correction is always (+) when the LL is used for observation and (-) when the UL is used.

6: UL or LL is only applicable for the Sun and the Moon because they appear as large discs to the observer. He cannot judge the location of the centre of the visible disc. Hence he has to observe the altitude of the UL or LL and then apply suitable correction to obtain the altitude of the centre of the Sun or Moon. Stars and planets are so far away that they only appear as pin points to the observer. Hence LL or UL is not applicable for stars and planets.

7: For STARS & PLANETS, total correction is given in a separate table from the Sun and is always to be subtracted.

8: In the case of Venus and Mars, one more correction called 'Additional correction' is to be applied. This is given in the Nautical Almanac tabulated against altitude.

10.2 Correction of altitudes of the MOON:-

The apparent altitude is obtained as explained in 10.1. Total correction for the Moon is given in the inside part of the back cover of the Nautical Almanac. The method of use of those tables is clearly illustrated therein and two solved examples will illustrate this fully:

Given: Sext alt of Moon's LL 42° 24.6', IE 2.4' on the arc, HE 12m, HP 54.6' Find the true altitude.

Sext alt	42° 24.6'
IE	(-) 2.4'
Obs alt	42° 22.2'
Dip (HE 12m)	(-) 6.1'
App alt	42° 16.1'
Main corr	(+) 52.2'
HP corrn (54.6)	(+) 01.9'
T altitude	43° 10.2'

Given: Sext alt of Moon's UL 56° 27.1', IE 3.8' off the arc,. HE 15m, HP 56.0'. Find the true altitude.

Sext alt	56° 27.1'
IE	(+) 3.8'
Obs alt	56° 30.9'
Dip (HE 15m)	(-) 6.8'
App alt	56° 24.1'
Main corr	(+) 41.9'
HP corrn (56.0)	(+) 03.2'
	57° 09.2'
	(-) 30.0'
T altitude	56° 39.2'

NOTES

1: HP stands for Horizontal Parallax of the Moon. It is obtained from that day's page of the Almanac, alongside the declination.

2: Both main and HP corrections are always positive.

3: For UL, 30' has to be subtracted from the total to get true altitude.

10.3 Back angle observations:

Sometimes, the horizon under the celestial body may not be clearly visible owing to the presence of land, haze, mist, rain, etc. In such cases, it may be possible to observe the altitude of the body in the opposite direction i.e., if the azimuth (bearing of the celestial body) is 080°, the altitude is taken while facing 260°. Since the observer would then have his back to the celestial body, such a measurement is called a 'Back angle' observation.

Back angle observations will always be greater than 90°. However, the sextant cannot measure angles greater than 120°. Hence back angle observations will be between 90° and 120°.

Worked example 1 - Back angle - stars & planets:

Given: On 20th Dec 1992, Sext alt of Venus was 118° 52.3'. IE 3.6' off the arc, HE 20m. Required: The true altitude.

Sext alt	118° 52.3'	
IE	(+) 3.6'	[As usual]
Obs alt	118° 55.9'	
Dip (HE 20m)	(-) 07.9'	[As usual]
App alt	118° 48.0'	
	61° 12.0'	[Subtract from 180°]
Tot. corrn	(-) 00.5'	[As usual]
	61° 11.5'	
Addl corrn	(+) 00.1'	[Mars & Venus only]
T alt	61° 11.6'	

Worked example 2 - Back angle Sun:

Total correction cannot be used here. The individual corrections - Dip, Refraction, Semi- diameter and Parallax have to be applied separately. Slogan for easy remembrance: Don't Rob Spare Parts.

Given: Sext alt of Sun's LL was 119° 11.6'. IE 2.8' on the arc, HE 12m, date 30th Nov 1992. Required: True altitude.

Sext alt	119° 11.6'	
IE	(-) 2.8'	[As usual, on arc (-)]
Obs alt	119° 08.8'	
Dip (HE 12m)	(-) 06.1'	[As usual, always (-)]
App alt	119° 02.7'	
	60° 57.3'	[Subtract from 180°]
Refraction	(-) 00.5'	[As usual, always (-)]
	61° 56.8'	
Semi-diam*	(-) 16.2'	[Opposite, LL (-)]*
	61° 40.6'	
Parallax	(+) 00.1'	[As usual, always (+)]
True alt	61° 40.7'	

NOTES

1: The correction for refraction can be obtained from the Nautical Almanac or from Nautical Tables. Since stars and planets do not have any semi-diameter or parallax, the total correction tabulated in the Nautical Almanac consists entirely of refraction. So to get the refraction correction for the Sun, as in this case, look up the total correction for stars. This is tabulated against apparent altitude in the Nautical Almanac.

2: The value of the semi-diameter of the Sun is given at the foot of that day's page in the Nautical Almanac. In back angle observations, correction for SD is applied opposite - Normally LL +, UL -, but in this case, LL -, UL +.

3: The correction for parallax is given in Nautical Tables.

-o0o-

11

DAY'S WORK

Day's Work is a summary of the ship's passage from 1200 hours on one day to 1200 hours the next day (ship's time). The working is illustrated by worked examples with explanatory notes where required.

Worked example 1

At noon on 14th Sept., a ship in position 40° 12'N 76° 46'W set course of 250°(C) - Dev 4°W, Var 6°W - at an engine speed of 16 knots. At 1600, course was altered to 287°(C) - Dev 2°E, Var 6°W - and the speed was decreased to 14 knots. At 2200, course was again altered to 340°(C) - Dev 5°E, Var 5°W - and speed of 14 knots was maintained till 0600 next morning, when course was altered to 277°(C) - Dev 2°W, Var 5°W - and speed increased to 15 knots. This course and speed was maintained till noon on 15th Sept. Find the EP on 15th noon, the course and the distance made good, if a current was setting 027°(T) at 2 knots throughout.

Note: This is called the narrative or linear form of question. All courses should be tabulated and corrected first, as follows:

	1200 to 1600	1600 to 2200	2200 to 0600	0600 to 1200	Current
Compass Co	250°(C)	287°(C)	340°(C)	277°(C)	
Deviation	4°W	2°E	5°E	2°W	
Magnetic Co	246°(M)	289°(M)	345°(M)	275°(M)	
Variation	6°W	6°W	5°W	5°W	
True Co	240°(T)	283°(T)	340°(T)	270°(T)	027°(T)
	S60°W	N77°W	N20°W	W	N27°E
Distance	64M	84M	112M	90M	48M

Note: Set of current is taken as a course and the drift for the whole 24 hour period is taken as distance. All the true courses are converted into their quadrantal figures so that TT can be entered. Quadrantal figures also give the names of d'lat and d'long.

The distance run on each course is entered in the lowest line just beneath the corresponding course in quadrantal figures. The last two rows in the foregoing table should be used to enter TT and the information tabulated as follows:

Course (T)	Dist M	d'lat N	d'lat S	dep E	dep W
S60°W	64		32.0		55.4
N77°W	84	18.9		81.8	
N20°W	112	105.2		38.3	
W	90				90.0
N27°E	48	42.8		21.8	
Total		166.9	32.0	21.8	265.5
		32.0			21.8
Resultant		134.9			243.7

Note: After obtaining total d'lat and total dep in each direction, the smaller figure of d'lat is transferred under the larger figure of d'lat and the `Resultant d'lat' is obtained by subtraction. `Resultant dep'

is also obtained similarly. Entering TT with resultant d'lat and resultant dep, the course and distance made good, noon to noon, is obtained (as explained in Chapter 6.2).

From TT:-

d'lat	dep	Co	Co	dist
134.9	243.3	61°	61°	278.2
134.9	253.8	62°	62°	287.2
	10.5 →	60'	60' →	9.0
	0.4 →	2'	2' →	0.3
134.9	243.7	61° 02'		278.2

Co MG = N61° 02'W and dist = 278.5 M **Answer (i).**

The EP next noon is obtained by TT as explained in Chapter 6.1.

N/N pos 14th lat	40° 12.0'N	long	76° 46.0'W	m'lat	41.3°
Resultant d'lat	02° 14.9'N	d'long	5° 24.6'W	dep	243.7'W
N/N EP 15th lat	42° 26.9'N	long	82° 10.6'W	d'long	324.6'W

Answer (ii).

Worked example 2

On 16th Jan a ship in position 00° 10'N 68° 09'E set course as follows:-

	Time	Co(C)	Dev	Var	L'way	Wind	Log
	1200	126°	2°E	4°E	3°	SW	0
a/c	1800	149°	3°E	4°E	2°	NE	89
a/c	2300	210°	1°W	5°E	3°	SE	168
a/c	0700	240°	2°W	5°E	Nil	W	290
a/c	1200	270°	Nil	4°E	3°	N	368

A current set the vessel 183°(T) at 1.5 knots throughout. Find the EP next noon and the course and distance made good.

NOTES

1: This is called the tabular form or Log extract form of presentation. It further differs from example 1 in that leeway is included. Since course actually steered is given, it is necessary to apply leeway and obtain the effective course (course made good with wind only) for each leg of run.

2: If the wind is coming from the starboard side of the ship, the ship would be blown off-course to port. So the effective course will be less than the true course steered (when expressed in the three figure notation), and vice versa - that is, if the wind is coming from the port side of the ship, the ship would be blown off-course to starboard. So the effective course will be more than the true course steered (in the three figure notation).

3: The distance steamed on each course is obtained by the difference of log readings taken at the beginning and at the end of each course.

4: The alteration of course to 270° shown against 1200 hours on 17th Jan would be effective from 1200 onwards and is hence not to be included in the working from 1200 on 16th Jan to 1200 on 17th Jan. The log reading at that time is, however, necessary to compute the distance run from 0700 to 1200 on the 17th.

	1200 to 1800	1800 to 2300	2300 to 0700	0700 to 1200	Current
Compass Co	126°(C)	149°(C)	210°(C)	240°(C)	
Deviation	2°E	3°E	1°W	2°W	
Magnetic Co	128°(M)	152°(M)	209°(M)	238°(M)	
Variation	4°E	4°E	5°E	5°E	
True Co	132°(T)	156°(T)	214°(T)	243°(T)	
Leeway	3°	2°	3°	Nil	
Effective Co	129° (T)	158°(T)	217°(T)	243°(T)	183°(T)
	S51°E	S22°E	S37°W	S63°W	S03°W
Distance	89M	79M	122M	78M	36M

The rest of the working is similar to that of example 1:

Effective Co (T)	Dist M	d'lat N	d'lat S	dep E	dep W
S51°E	89		56.0	69.2	
S22°E	79		73.2	29.6	
S37°W	122		97.4		73.4
S63°W	78		35.4		69.5
S03°W	36		36.0		01.9
Total			298.0	98.8	144.8
		00.0		98.8	
Resultant			298.0		46.0

From TT, Co MG = S08° 47'W, dist MG = 301.5 M **Answer (I).**

N/N pos 16th lat	00° 10.0'N	long	68° 09.0'E	m'lat	02.3°S
Resultant d'lat	04° 58.0'S	d'long	0° 46.0'W	dep	46.0'W
N/N EP 17th lat	04° 48.0'S	long	67° 23.0'E	d'long	46.0'W

Answer (ii).

Note: Since m'lat is only 2.3°, TT shows dep = d'long = 46'.

Worked example 3

On 6th March a ship in position 46° 36'S 175° 34'E steamed the following courses:-

Time	Co(C)	Dev	L'way	Wind	Speed
1200	150°	5°E	3°	SWxW	8 Kn
1600	140°	4°E	5°	SW	8
2000	120°	3°E	Nil	SW	7.5
2400	120°	3°E	Nil	SW	6.5
0400	100°	1°E	Nil	S	8
0800	095°	Nil	Nil	S	8
1200	095°	Nil	Nil	S	8

Var 10°E throughout. Find the DR position at noon on 7th March and, if the observed position then was 48° 14.3'S 178° 06.5'E, find the set and drift of current.

Note 1: The DR next noon should be worked out as shown in examples 1 and 2. Since Co and dist MG are not asked, they need not be calculated. It is implied that the alteration of course, in each case, is at the hour mentioned alongside. For example: 140°(C) was set at 1600 hours. 120°(C) was set at 2000 hours, and so on.
Note 2: There is no alteration of course at 2400 hours but the speed has altered. So from 2000 to 2400, the distance will be 30M and from 2400 to 0400 it will be 26M. Hence from 2000 to 0400, the distance will be 56 M on a course of 120°(C).

	1200 to 1600	1600 to 2000	2000 to 0400	0400 to 0800	0800 to 1200
Compass Co	150°(C)	140°(C)	120°(C)	100°(C)	095°(C)
Deviation	5°E	4°E	3°E	1°E	Nil
Magnetic Co	155°(M)	144°(M)	123°(M)	101°(M)	095°(M)
Variation	10°E	10°E	10°E	10°E	10°E
True Co	165°(T)	154°(T)	133°(T)	111°(T)	105°(T)
Leeway	3°	5°	Nil	Nil	Nil
Effective Co	162° (T)	149°(T)	133°(T)	111°(T)	105°(T)
	S18°E	S31°E	S47°E	S69°E	S75°E
Distance	32M	32M	56M	32M	32M

Effective Co (T)	Dist M	d'lat N	d'lat S	dep E	dep W
S18°E	32		30.4	09.9	
S31°E	32		27.4	16.5	
S47°E	56		38.2	41.0	
S69°E	32		11.5	29.9	
S75°E	32		08.3	30.9	
Total and resultant			115.8	128.2	

N/N pos 06th lat	46° 36.0'S	long	175° 34.0'E	m'lat	47.5°
Resultant d'lat	01° 55.8'S	d'long	03° 10.0'E	dep	128.2'E
N/N DR 07th lat	48° 31.8'S	long	178° 44.0'E	d'long	190.0'E

DR N/N 07th lat	48° 31.8'S	long	178° 44.0'E	Using T .T :-	
Fix N/N 07th lat	48° 14.3'S	long	178° 06.5'E	m'lat	48.4° S
d'lat	17.5'N	d'long	37.5'W	dep	24.9' W

Set = N55° 00'W and **drift** = 30.5M.

Worked example 4

At noon on 14th Dec a light house in lat 05° 56'N 80° 36'E bore 000°(C), error 4°W, distance 10 M. Course was then set to 220°(C), Dev 1°E, Var 2°W, log 0. At 2000, engines broke down and the log, showing 82, was hauled in. At 2200, engines were repaired and course was reset to 200°(C) Dev nil, Var 2°W, log 0. Ship maintained this course till noon next day when log showed 140. A current was estimated to set 350°(T) at 2 knots throughout. Find the EP at noon on 15th Dec.

NOTES

1: There are two differences in this question from those illustrated earlier. Firstly, the noon position on starting is not given directly and secondly, an engine stoppage is given.

2: Since the current was constant, even during engine stoppage, it is allowed as a course and distance for the whole day as usual.

First obtain the noon position on 14th Dec as follows:

Bearing of Lt Ho from ship: 000° (C)
Compass Error ..... 4° W
Bearing of Lt Ho from ship: 356° (T)
Bearing of ship from Lt Ho: 176° (T)
i.e., Course S04°E & distance 10 M.

3: Sometimes the bearing **of the ship from the light house** is given. In that case **do not reverse the bearing**, but use the given bearing as the course, as illustrated below:

Pos of Lt Ho	lat	05° 56.0'N	long	80° 36.0'E	m'lat 5.9°N
S04°E - 10 M	d'lat	10.0'S	d'long	0.7'E	dep 0.7'E
Noon pos 14th	lat	05° 46.0'N	long	80° 36.7'E	

	1200 to 2000	2000 to 2200	2200 to 1200	Current
Compass Co	220°(C)		200°(C)	
Deviation	1°E		Nil	
Magnetic Co	221°(M)		200°(M)	
Variation	2°W		2°W	
True Co	219°(T)		198°(T)	350°(T)
	S39°W		S18°W	N10°W
Distance	82M		140M	48M

The working of the rest of the problem is similar to those illustrated earlier. The student may work it out on his own.

Answer: EP 15th noon lat 03° 16.5'N long 78° 53.0'E.

Worked example 5

At noon on 20th July, Pargo Point (32° 48'N 17° 16'W) bore 080° (C) 10 M off while steaming 219° (C), Dev 3° E Var 18° W. Ship maintained this course at a steady speed of 15 knots till noon next day. Clocks were retarded 12 minutes at 0200 hours. Find the DR at 1200 hours on 21st July. If the fix then was 27° 12'N 20° 05'W, find the set and drift of current.

Note: This question is different from the previous ones only in one aspect - alteration of clocks. The steaming time from 1200 on 20th July to 1200 on 21st July becomes 24h 12m because clocks were

retarded 12 minutes. If clocks were advanced, the steaming time would be reduced accordingly.

Distance at 15 knots, for 24h 12m steaming, is 363M. The rest of the working is similar to that of example 3.

Answer:- DR 27° 12.2'N 20° 17.4'W - Set 091° (T), drift 11 M.

Worked example 6

A ship steams the following courses by Gyro compass, error nil :-

13th Jan	1200 - Co 236° (G)	speed 15.0 knots
a/c	1700 - Co 284° (G)	speed 16.0 knots
a/c	2000 - Co 262° (G)	speed 15.0 knots
14th a/c	0400 - Co 198° (G)	speed 14.5 knots

and continued thus till noon, 14th Jan.

At 1800 on 13th Jan, a light house in 48° 28.5'N 67° 05'E bore 4 points on the starboard bow and at 1845 it was abeam. Find the 14th noon DR, the course and distance made good noon to noon.

Note: This is very simple if approached systematically. First the course and distance made good noon to noon can be got as usual. Since the courses are true, with no leeway, working is simplified.

	Course (T)	Dist M	d'lat N	d'lat S	dep E	dep W
1200 - 1700	S56°W	75		41.9		62.2
1700 - 2000	N76°W	48	11.6			46.6
2000 - 0400	S82°W	120		16.8		118.8
0400 - 1200	S18°W	116		110.3		35.8
	Total		11.6	169.0		263.4
				11.6		Nil
	Resultant			157.4		263.4

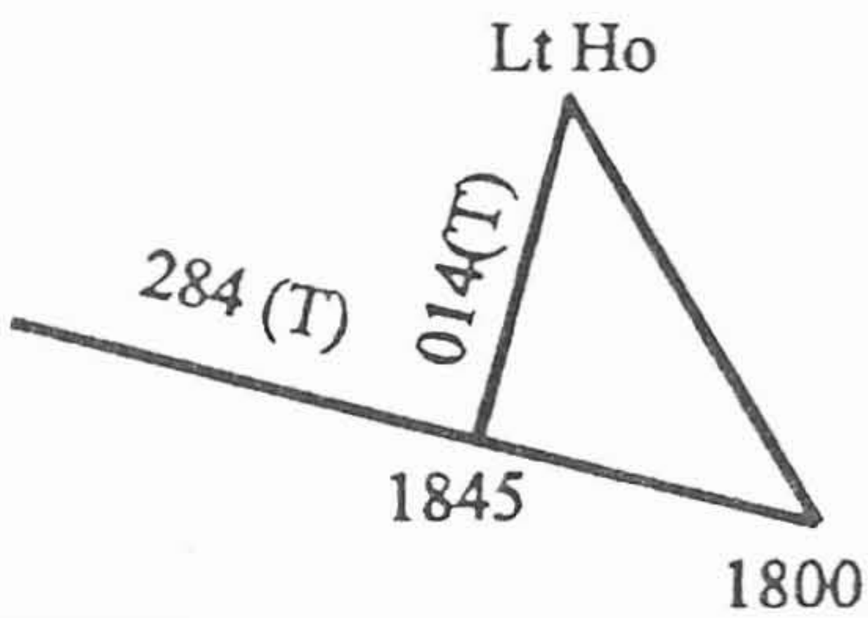
From Traverse Tables:-

d'lat	dep	Co	Co	dist
157.4	262.0	59°	59°	305.6
157.4	272.6	60°	60°	314.8
	10.6→	60'	60' →	9.2
	1.4→	8'	8' →	1.2
157.4	263.4 →	59° 08'	→	306.8

Answer (i): Course MG = S59° 08'W Dist MG = 306.8 M.

To calculate the pos of the ship at 1845 hrs:-

Co between 1800 and 1845	=	284°(T)		
Starboard beam	=	+90°		
1845 beam bearing of Lt from ship	=	374°(T)	=	014°(T)
1845 bearing of ship from Light	=	194°(T)	=	S14°W



By the principle of doubling the angle on the bow, distance steamed from 1800 to 1845 is the distance off abeam at 1845. Distance for 45 minutes at 16 knots = 12 M = distance off at 1845 on a bearing of S14°W from the light house.

Pos of Lt Ho	lat 48° 28.5'N	long 67° 05.0'E	m'lat 48.4°N
S14°W - 12M	d'lat 11.6'S	d'long 4.3'W	dep 2.9'W
1845 position	lat 48° 16.9'N	long 67° 00.7'E	

NOTES

1: From 1845 to the next a/c at 2000 Co = 284°(T) & dist = 20M.
2: D'lat and dep for the run on each leg after 2000 can be copied from the earlier table made for the noon to noon Co and dist.

	Course (T)	Dist M	d'lat N	d'lat S	dep E	dep W
1845 - 2000	N76°W	20	04.8			19.4
2000 - 0400	S82°W	120		16.8		118.8
0400 - 1200	S18°W	116		110.3		35.8
	Total		04.8	127.1		174.0
				04.8		Nil
	Resultant			122.3		174.0

1845 pos of ship	48° 16.9'N	long	067° 00.3'E	m'lat	47.25°N
Resultant d'lat	02° 02.3'S	d'long	04° 16.3'W	dep	174.0'W
N/N DR 14th lat	46° 14.6'N	long	062° 44.4'E	d'long	256.3'E

Answer (ii)

Note: Owing to the large number of worked examples included here on Day's Work, no separate exercise is given in this chapter. Students desiring to practice Day's Work can work out the same lot without copying the working shown here and compare the answers.

-o0o-

12

CHRONOMETER

TIME

12A: THE AMBIGUITY OF CHRONOMETER TIME

Most chronometers are graduated like ordinary clocks i.e., from 0 to 12 hours only. So if chronometer shows 4h, it could be 04h or 16h, creating a twelve hour ambiguity. So whenever chronometer time is given in a navigation problem, it should be checked before commencing the calculation.

If GMT is given, no 12h ambiguity exists as GMT is expressed in the 24 hour notation - 4h means 04h NOT 16h.

Remember: **GMT hours - accept. Chron hours - suspect.**

On modern ships, GMT for celestial observations is taken from the navigation satellite receiver instead of the chronometer. In such cases, the date and exact GMT in the 24-hour notation would be known directly without any ambiguity.

The reason why the ambiguity in chronometer time is still retained in the examination system is that the student is constantly reminded that he should check the input data before plunging into calculations. GMT is also called UTC-Universal Time Coordinate

The date given in a problem usually refers to the date on the ship NOT the GMT date or chronometer date. Hence this has to be checked as the GMT date may possibly be one day less or more than the date kept on the ship. This is illustrated below:-

On 24th June at 0500 IST in Bombay, GMT would be 05h 30m less i.e., 23d 23h 30m. Yet, one hour later, at 0600 IST on 24th, GMT would be 24d 00h 30m.

In E long, GMT may be same date as ship or one day behind.
In W long, GMT may be same date as ship or one day ahead.

The procedure for solving the ambiguity is as follows:

(1) Write down the two possibilities of chronometer time.
(2) Apply LIT (longitude in time) to each and obtain both the possibilities of LMT hours.
(3) An indication whether it is A.M or P.M on the ship would be given/known. Insert the date on the ship alongside appropriate LMT and, working backwards, insert the date of GMT.

Example: On 13th Sept, PM at ship in DR 27° 16'N 75° 00'W, the chron showed 03h 18m 12s, error 02m 05s fast. Find GMT.

		h	m	s			h	m	s
Chron		03	18	12		or	15	18	12
Error □		(-)	02	05			(-)	02	05
GMT	(14)*	03	16	07			15	16	07
LIT (W)	(-)	05	00	00	Δ		(-)	05	00	00
LMT	(13)*	22	16	07			10	16	07

GMT: 14d 03h 16m 07s

□ Application of error is described in 12B. * Inserted last.

Δ If direct subtraction not possible, 24h to be added.

In problems in practical navigation, AM or PM at ship, or the approximate ship's time, MUST be given. However, as a point of interest, it is possible to resolve the 12 hour ambiguity by other means which have fondly been called navigational gymnastics:-

(a) **For azimuth, long by chron and intercept - SUN:-**
The correct LMT must be after sunrise and before sunset, both of which are obtained from that day's page in the nautical almanac.

(b) **For ex-meridian alt - SUN:-** The correct LMT must be very near 1200 hrs (between 1030 and 1330 or so).

(c) **For azimuth - STARS AND PLANETS:-**
The correct LMT must be at night ie. after sunset and before sunrise (both obtained from that day's page of the nautical almanac) as they are not visible during daytime.

(d) **For sextant observations - STARS & PLANETS:-**
From that day's page of the nautical almanac, extract the civil and nautical twilight timings and tabulate them thus :-

The correct LMT will be between Civil and Nautical twilight of either A.M or P.M only.

	A.M	P.M
CIVIL	0540	1905
NAUT	0510	1930

If, in one chance in a million, A.M and P.M are both possible, the question would involve "superior navigational gymnastics."

(e) **For ex-meridian alt - STAR:-**
Calculate the approx. LMT mer pass star as follows :-

LMT mer pass γ :	03h 17.6m
SHA ★ in time (-)	09h 16.3m
LMT mer pass ★	18h 01.3m

(From the corresponding page of the Almanac).

The correct LMT must be very close to the time calculated above. The time so calculated will give only an approximate idea of the LMT meridian passage of the star and cannot be used for any other purpose other than to sort out ambiguity of chronometer time.

(f) **For ex-mer alt - PLANETS AND MOON:-**
The approx LMT of mer pass is given in that day's page of the Nautical Almanac and the correct LMT must be near that.

(g) **For azimuth, long by chron and intercept - MOON:-**
Correct LMT must be between approx. LMT of moonrise and moonset, both of which are given in that day's page of the Nautical Almanac.

(h) **For ex-mer alt - MOON:-**
Approx. LMT mer pass moon is given in that day's page of the Nautical Almanac. Correct LMT must be close to this.

12 B: PROBLEMS INVOLVING DAILY RATE OF CHRON

The difference between chronometer time and GMT, at any instant, is called the **chron error.** Chron error is said to be FAST if the chron time is ahead of GMT. Fast error is, therefore, to be subtracted from chron time to obtain GMT. Chron error is said to be SLOW if the chron time is behind GMT. Slow error is, therefore, to be added to chron time to obtain GMT.

The words FAST and SLOW only indicate whether the chronometer is ahead of GMT or behind it. They do NOT indicate the speed of the chronometer. The words GAINING or LOSING are used to indicate the speed of the chronometer.

A chronometer is said to be GAINING in the following cases:
(1) If the chron is correct on GMT one day and is fast next day.
(2) If it is fast one day and more fast the next day.
(3) If it is slow one day and less slow next day.
(4) If it is slow one day and fast next day.

A chronometer is said to be LOSING in the following cases:
(1) If the chron is correct on GMT one day and is slow next day.
(2) If it is slow one day and more slow the next day.
(3) If it is fast one day and less fast next day.
(4) If it is fast one day and slow next day.

The **daily rate** of the chronometer is the number of seconds gained or lost by it in one day. It is usually taken as an average over a number of days to overcome observational errors and thereby obtain an accurate result. A good, reliable chronometer may not keep perfect time but will have a constant daily rate by which GMT can be computed at any required instant.

Over a period of time, the change of chron error (caused by daily rate) is called the **accumulated rate**. Accumulated rate is obtained by multiplying the daily rate by the interval between the time of the last time signal and the required date and time as illustrated in the following worked examples.

If the daily rate is gaining, the accumulated rate would be called fast and if the daily rate is losing, accumulated rate would be called slow. Accumulated rate, applied to the old chron error, would give the chron error at the required instant.

Worked Example 1

At 1200 GMT on 23rd June 1992, a chronometer was 6m 20s fast. Find the chron error at 0700 GMT on 4th August if the daily rate was 3s losing.

23rd June 1200 GMT to 30th June 1200 GMT:	07d	00h
30th June 1200 GMT to 31st July 1200 GMT:	31d	00h
31st July 1200 GMT to 04th Aug 0700 GMT:	03d	19h
23rd June 1200 GMT to 04th Aug 0700 GMT:	41d	19h
Interval:	41.8d*	

Accumulated rate = daily rate x interval = 3 x 41.8 = 125s Δ

* Squaring off to one decimal of a day would suffice.

Δ Squaring off to nearest second would suffice.

Accumulated rate	= 02m 05s (Slow)
Old chronometer error	= 06m 20s (Fast)
Error at GMT Aug 04d 07h 00m	= 04m 15s (Fast)

The interval can be calculated in an easier way by using page 5 of the Nautical Almanac as follows:-

04th Aug	0700 GMT	=	217th day of 1992	0700 GMT
23rd Jun	1200 GMT	=	175th day of 1992	1200 GMT
	Interval	=	41days	19hours
		=	41.8 days.	

In problems in practical navigation, it is essential to first **obtain the correct GMT date and hours of the astronomical observation** (as shown earlier in this chapter) so that the correct interval is obtained in days and hours. It would be considered an error in principle if this was not done first. This is illustrated in worked example 2.

Worked example 2

On 29th Nov, AM at ship in DR 26° 27'N 130° 27'W, an astronomical observation was made when the chron showed 05h 46m 20s. If at 0600 GMT on Oct 14th the chron was 00m 10s fast, and its daily rate was 4s losing, find the correct GMT of the observation.

	d	h	m	s		d	h	m	s
Chron		05	46	20	OR		17	46	20
Error	Not yet calculated								
Approx GMT		05	46	20		29	17	46	20
LIT (W)	(-)	08	41	48		(-)	08	41	48
LMT		21	04	32		29	09	04	32

Correct GMT d & h : 29d 17h

29th Nov	1746 GMT	=	334th day of 1992	1746 GMT
14th Oct	0600 GMT	=	288th day of 1992	0600 GMT
	Interval	=	46 days	11h 46m
		=	46.5 days.	

Accumulated rate = daily rate x interval = 4 x 46.5 = 186s SLOW

Accumulated rate	=	03m 06s (Slow)
Old chronometer error	=	00m 10s (Fast)
Error at GMT Nov 29d 17h 46m	=	02m 56s (Slow)

Chron time of observation	29 17 46 20
Chron error (Slow)	(+) 02 56
Correct GMT of observation	29 17 49 16

EXERCISE 4

(Accumulated rate of chronometer)

1 On 8th March 1992, AM at ship in DR 50° 12'N 176° 18'E, the chron showed 06h 01m 10s. If at 1200 GMT on 20th Feb chron error was 3m 12s fast and its daily rate was 5s gaining, find the correct GMT of the observation.

2 At about 1820 at ship in DR 20° 18'S 120° 11'W on 18th April 1992, find the correct GMT when chron showed 02h 21m 06s. Chron error on 30th March at 0600 GMT was 00m 40s slow and its daily rate was 2s gaining.

3. On Jan 4th 1992, PM at ship in DR 16° 01'N 84° 00'E, an astronomical observation was made when chron showed 01h 15m 10s. If chron error at 1800 GMT on 20th Dec 1991 was 10m 16s slow, and its daily rate was 6s gaining, find the correct GMT. (Note: Page 5 of the 1992 almanac cannot be used here).

13

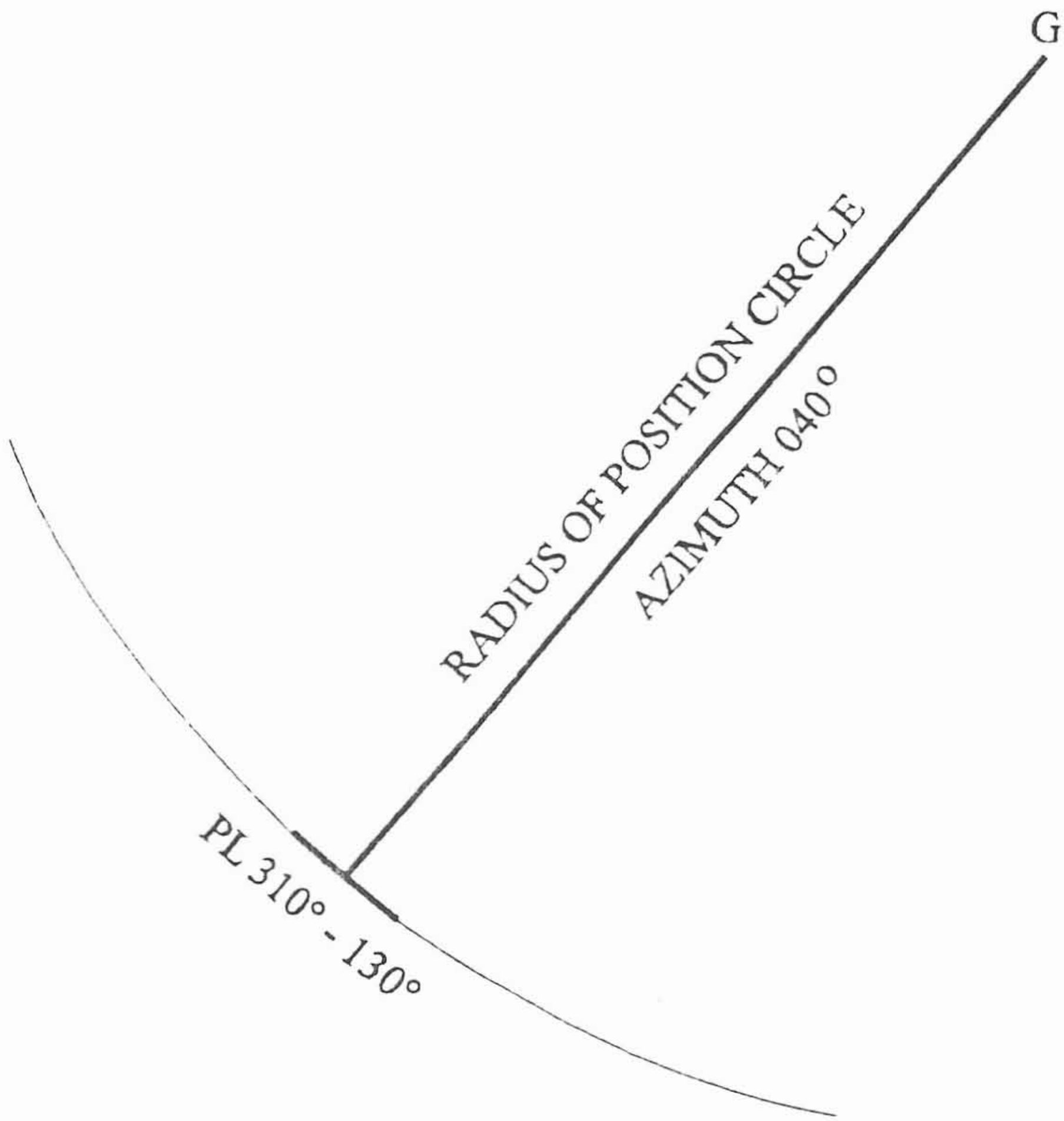
THEORY OF ASTRONOMICAL POSITION LINES

An astronomical position line is really a part of a large circle drawn on the surface of the earth, with its centre at the Geographical Position (GP) of the body and having a radius equal to the Zenith Distance. (GP and ZD have been described in Chapters 2 & 3). All observers on the circumference of this circle will observe that the body has the same ZD at the same time.

Since this circle has a large radius, any small part of the circumference of this position circle may be considered to be a straight line and called a position line (PL) or line of position (LOP). The azimuth (true bearing) of the celestial body, from the observer, represents the direction of the radius. Since the circumference of a circle and its radius meet at right angles, we say that the celestial PL (or LOP) is at right angles to the azimuth.

The azimuth of the body is easily calculated with the help of ABC tables using the DR position. The direction of the celestial PL (or LOP) is obtained by adding and subtracting 90° to the

azimuth - e.g., if azimuth was calculated to be 040°, the direction of the PL (or LOP) would be 130° - 310°.



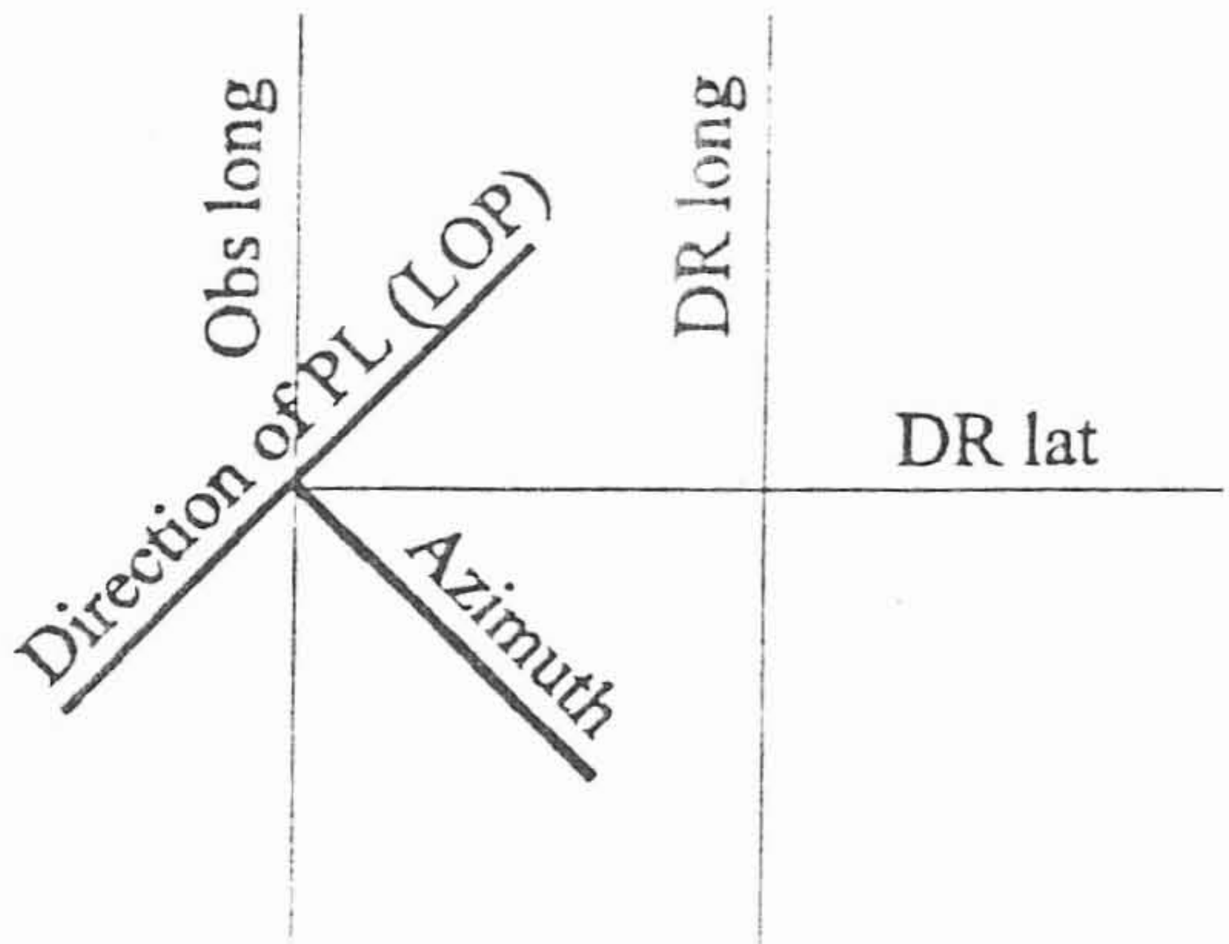
One astronomical observation can only give one PL (or LOP) and a position through which to draw it. Another PL (or LOP) is necessary to intersect the first PL (or LOP) in order to obtain a 'Fix'. There are five common methods of obtaining the position through which to draw the astronomical PL (or LOP) - (1) Latitude by meridian altitude, (2) Longitude by chronometer, (3) Intercept, (4) Ex-meridian and (5) Altitude of Polaris. Each of these is briefly described here:-

(1) **Latitude by meridian altitude:** Here the altitude of a celestial body is taken when the body is on the observer's meridian. Its azimuth at that time would be either 000° or 180°.

The PL (or LOP) will, in both cases, be 090° ↔ 270°.
(i.e., 000° ± 90° = 090° ↔ 270° and 180° ± 90° = 090° ↔ 270°).

Since the PL (or LOP) runs E - W, it will coincide with a parallel of latitude. The actual value of that latitude is obtained by a simple calculation. Such an observation will give a definite value of the ship's latitude, irrespective of any error in the ship's DR position. The actual calculations are shown and explained in the worked examples under the appropriate heading in subsequent chapters.

(2) **Longitude by chronometer:** Using the Haversine formula, we calculate the Observed Longitude (longitude where the position circle cuts the DR latitude). The azimuth is calculated by use of ABC tables and the direction of the PL (or LOP) is obtained by adding and subtracting 90° to it. This PL (or LOP) is drawn through the DR latitude and Observed longitude. The DR longitude is of no consequence in this calculation. Actual calculation by this method is shown under the appropriate heading in subsequent chapters.



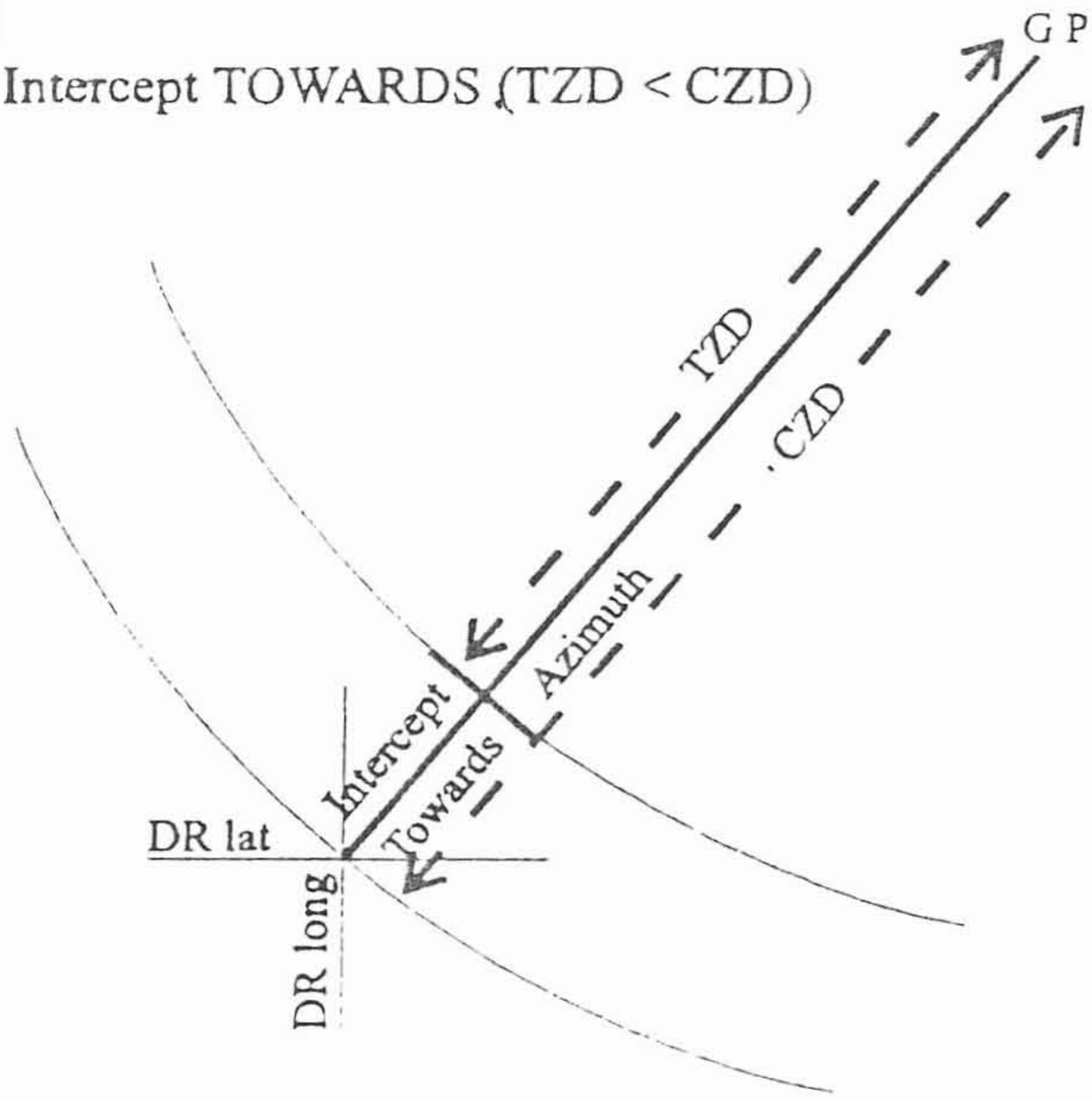
(3) **Intercept or Marcq St. Hilaire method:** The angular distance, between the DR position and the GP of the body, called the Calculated Zenith Distance (CZD), is calculated by use of the Haversine formula. CZD is then compared with the TZD (True Zenith Distance) which is obtained with the help of a sextant. The difference between them is called the intercept. Intercept is expressed in minutes of arc, taken to be Nautical Miles. The azimuth is calculated by using the DR position and ABC tables. The direction of the PL (or LOP) is obtained by adding and subtracting 90° to the azimuth.

The position circle always has the GP as its centre and ZD as its radius. The CZD is the radius of the position circle which passes through the DR position. The TZD is the radius of the position circle that passes through the actual position of the ship. Since we know the DR position of the ship, we imagine ourselves standing on the DR and going by the shortest distance to the true position circle. If **TZD < CZD**, we note that we will be going **towards** the GP (i.e., with azimuth as course and intercept as distance). If **TZD > CZD**, we will be going **away** from the GP (i.e., with a course equal to azimuth + 180° and with the intercept as distance. This is illustrated in the following figures.

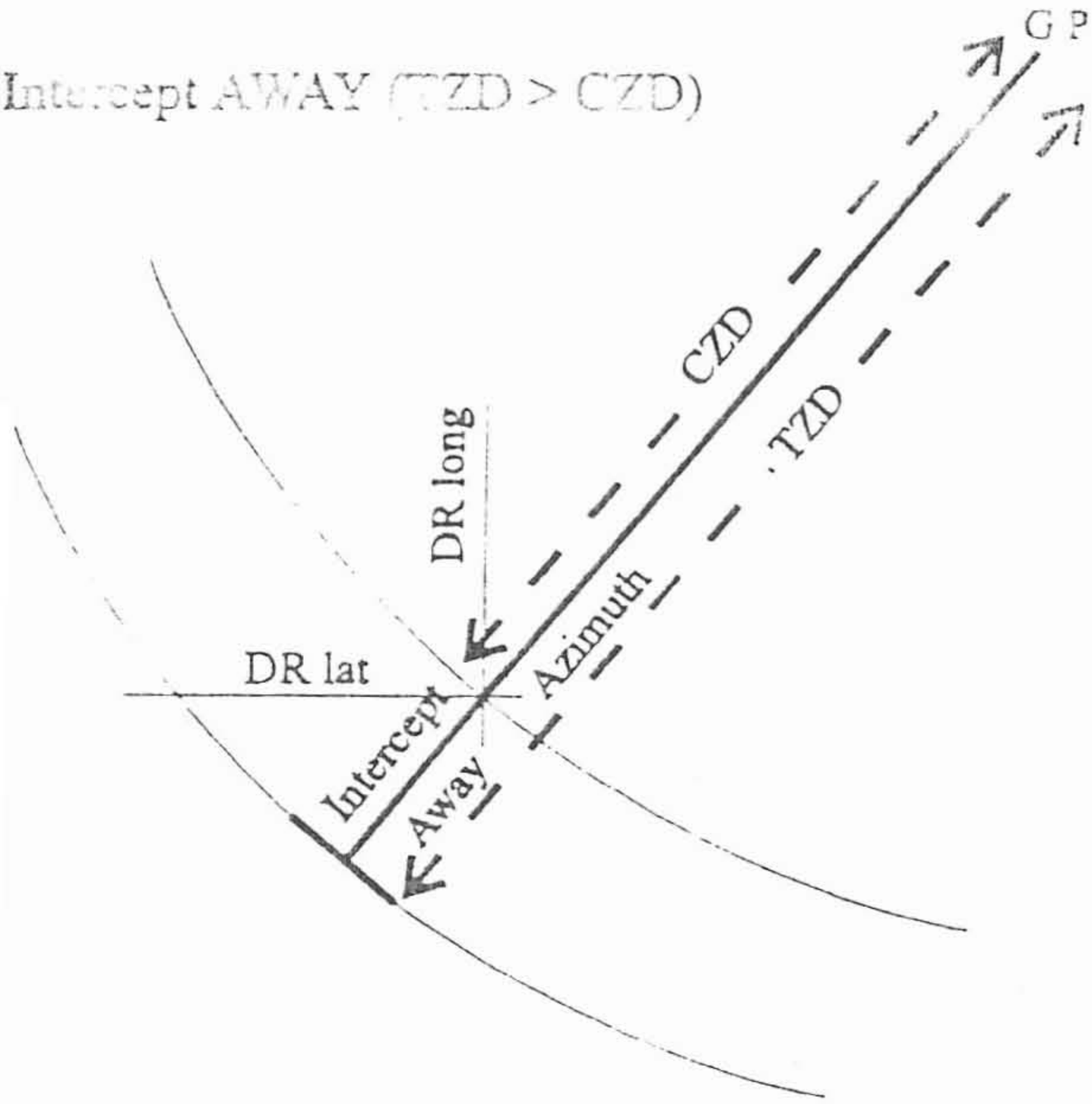
The solution of the intercept method of work should state the DR latitude, DR longitude, True Azimuth, the value of the intercept in minutes of arc, whether intercept is towards or away and finally the direction of the PL (or LOP). A rough figure (not necessarily to scale) should also be drawn as shown in the following examples 1 and 2.

The Intercept Terminal Point (ITP) is that point on the PL (or LOP) which is closest to the DR position. Calculation of the actual latitude and longitude of the ITP is not normally necessary and is done only if specifically asked to so.

Intercept TOWARDS (TZD < CZD)

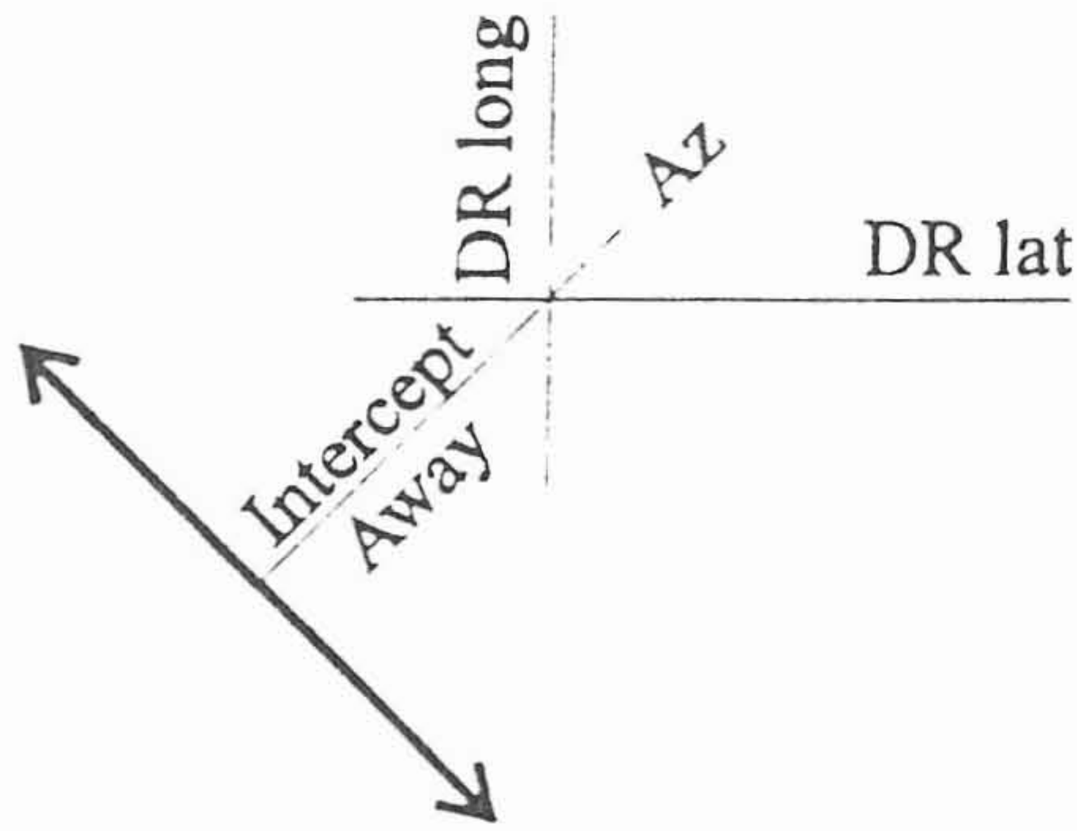


Intercept AWAY (TZD > CZD)



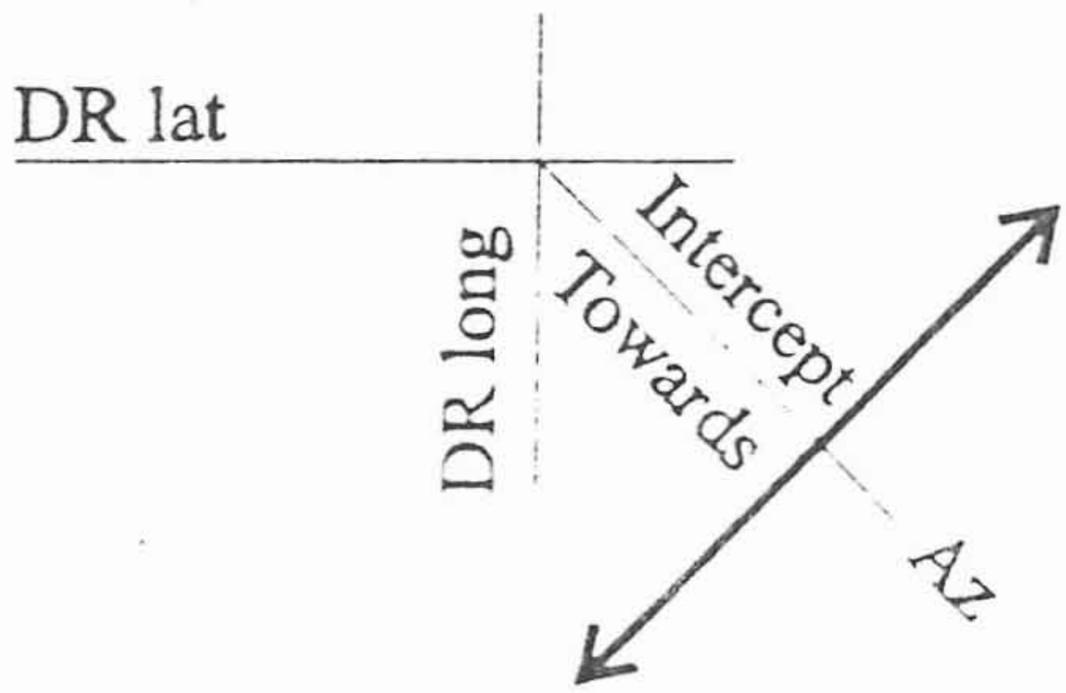
Example 1

DR position:
latitude: 36° 18'N
longitude: 72° 56'W
Intercept 3.8' AWAY
Az 042° (T)
PL 312° - 132°



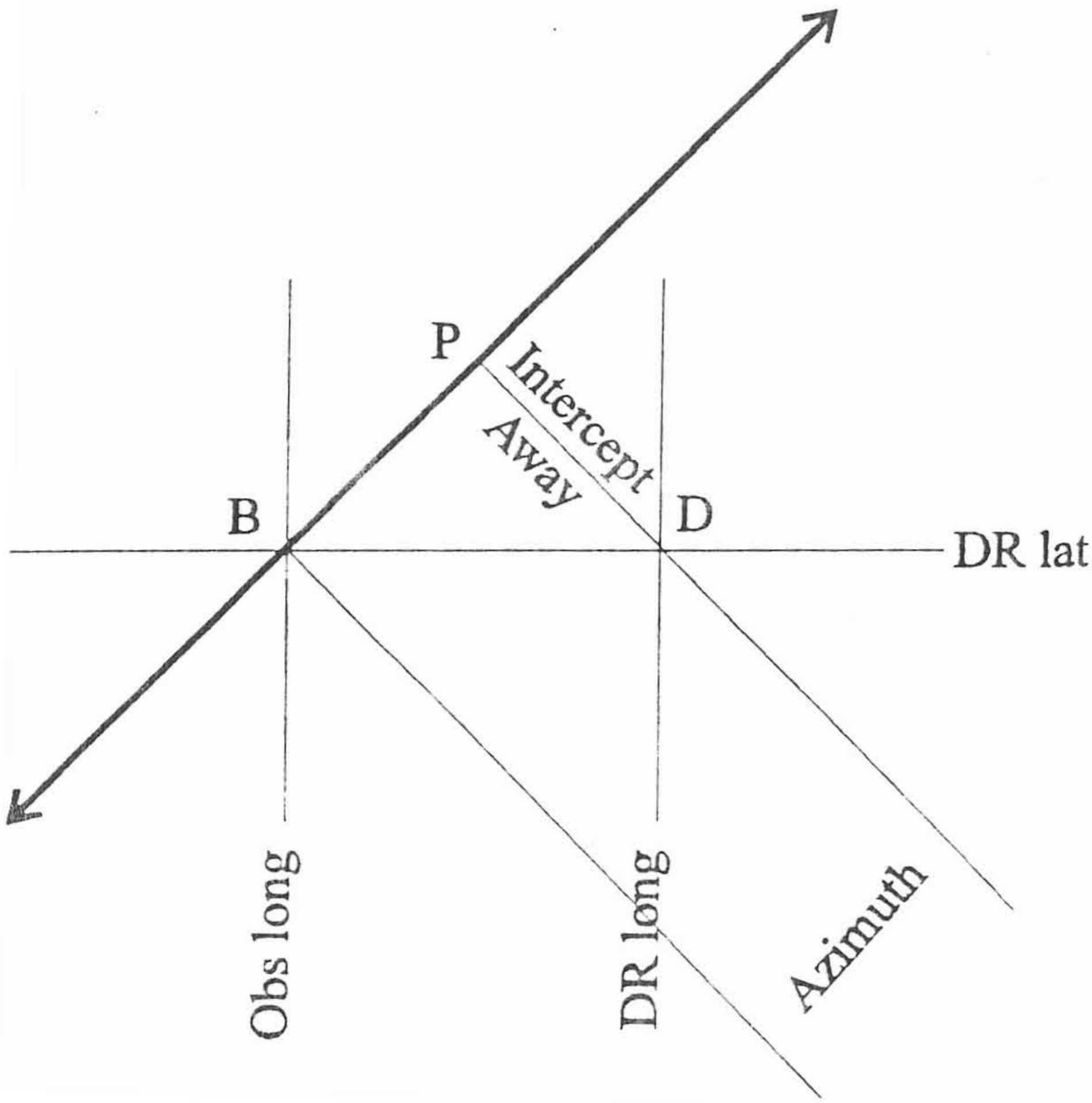
Example 2

DR position:
latitude: 16° 37`S
longitude: 142° 11`E
Intercept 4.5' TOW
Az 130° (T)
PL 220 ° - 040°



Both methods - Long by chron and Intercept - give equally accurate results and take the same time for working. In the examination, the choice of method is often left to the student but he should be thoroughly familiar with both these methods. The intercept method is much simpler and faster if several simultaneous observations are to be calculated and plotted to obtain a `Fix'.

The next figure illustrates the similarity of result of working by Long by chron and by Intercept. Using DR position `D', Obs long `B' and PL were obtained and plotted on a chart. If the same astronomical observation was worked by the intercept method, an intercept of DP would be obtained by calculation and, in the case illustrated, it would be `Away'.



As the celestial body is so far away, a few miles difference in the position of the observer would not appreciably affect the azimuth. So whether the azimuth was worked using the DR long or the Obs long, the answer would be the same and hence the direction of the PL (or LOP) of both, Long by chron and Intercept methods, would be the same. When the PL's (or LOP's) of both the methods are plotted on a chart, it will be observed that they coincide as shown in the foregoing figure. Actual working by the intercept method is shown under the appropriate heading in subsequent chapters.

(4) **Ex-meridian method:** Sometimes, it may not be possible to obtain the meridian altitude of a celestial body (especially the sun) owing to clouds, hazy horizon, rain or other causes. In such cases, it may be possible, under certain conditions (given below), to observe the body 'near the meridian' and, by use of Nautical Tables, calculate the latitude where the PL (or LOP) cuts the DR longitude (Observed latitude or Obs lat). The obs lat is not necessarily the latitude of the ship. The direction of the PL (or LOP) is obtained in the usual manner - calculating azimuth by ABC Tables and applying ± 90° to it.

The circumstances under which a sight may be worked by the ex-meridian method is governed by the values and names of the latitude and the declination. The value of the ex-meridian limit (EML) is obtained from Nautical Tables. In the case of Burton's Tables, EML is obtained by entering Ex-meridian Table IV. In the case of Norie's Tables, we have to consult Ex-meridian Tables I & IV to obtain EML. Ex-meridian Table I is in two parts - one for lat & dec having same name and the other for lat & dec having opposite names.

The EML so obtained will be in minutes of time. If the EML is found to be 16 minutes, it means that an ex-meridian sight may be taken upto 16 minutes on either side of the time of meridian passage, as illustrated below:-

Ship's time of meridian passage	1206
EML (from nautical tables)	± 16
Ex-mer sights may be taken between ship's time:-	1150 and 1222

A rough thumb rule is available to obtain the approximate value of EML without Nautical Tables:- calculate the L~D (Lat and Dec same names subtract and opposite names add), square off to the nearest whole number of degrees and just call that value the EML in minutes of time.

Example: DR lat 20°16'N dec 20°30'S. Approximate EML = ?
L~D = 41 whole degrees. Approximate EML = 41 minutes of time

For examination purposes, when a body is said to be 'Near the meridian', it is expected to be worked by the ex-meridian method. The solution to an ex-meridian problem should state the Obs lat, the DR long and the direction of the PL (LOP). Actual working of an ex-meridian problem is shown under the appropriate heading in subsequent chapters.

(5) **Polaris**:- is a star of very high declination (around 89° 09') and hence its azimuth is very nearly North at all times, resulting in a PL very nearly E-W. By applying special corrections (given in the Nautical Almanac) to the true altitude, the Obs lat (latitude where the PL cuts the DR longitude) is obtained. The true azimuth also is obtained from the same page of the Nautical Almanac. The direction of the PL is obtained as usual, by applying 90° to the azimuth. The solution to an altitude of Polaris should specify the Obs lat, the DR long and the direction of the PL, similar to the solution of an ex-meridian sight.

Note: The Obs lat obtained by an observation of Polaris is not necessarily the latitude of the vessel as the PL is **nearly** E-W **not** necessarily **exactly** E-W.

Polaris cannot be seen from the Southern Hemisphere or from very low latitudes in the Northern Hemisphere. In the former case it will be below the horizon and in the latter case, it will be above but too close to the horizon for observation by a sextant.

The actual working of an altitude of Polaris is shown under the appropriate heading later on in this book.

14

WORKED EXAMPLES

AND EXERCISES - SUN

14.1 Latitude by meridian altitude - Sun:-

On 23rd Sept 1992, in DR 23° 40'N 161°56'E, the sextant meridian altitude of the Sun's lower limb was 66° 10.6'. If IE was 2.3' on the arc and HE was 10.5m, find the latitude and the PL.

			From Almanac
Sext Alt	66° 10.6'	LMT mer pass	23d 11h 52m 00s
IE (on)	(-) 02.3'	LIT (E)	(-) 10 47 44
Obs alt	66° 08.3'	GMT mer pass	23d 01h 04m 16s
Dip (10.5m)	(-) 05.7'	Dec	00° 06.1' S
App alt	66° 02.6'	d (1.0)	(+) 00.1'
Tot corrn LL	(+) 15.5'	Dec	00° 06.2' S
T alt	66° 18.1' S	→ (Named same as azimuth)	
MZD	23° 41.9' N	→ (Named opposite to T alt)	
Dec	00° 06.2' S	→ (See note 1 below).	
Latitude	23° 35.7' N	PL :- E - W	

Notes

(1) MZD and dec are of **same name** so **add** and retain name. If of **opposite names, subtract** the smaller one from the larger one and retain the name of the larger one.

(2) Corrections to sext alt are explained in Chapters 9 and 10.

(3) In the above example, DR lat is 23° 40'N while dec is practically nil. Hence the sun's Az at mer pass must be S and so the true altitude is named S and MZD is named N. This naming system is a quick and sure method of finding out whether MZD and dec are to be added or to be subtracted to obtain the latitude without the necessity of drawing a figure to reason this out.

(4) Whether MZD and dec are to added or subtracted can, in many cases, be decided by knowing that the answer must be very close to the DR lat. However, if either MZD or dec is very small, both addition and subtraction would give results reasonably close to DR lat, as in the foregoing worked example, and the unwary student would be puzzled as to what to do. A mistake of this sort is considered a 'Principle Error' in the examination, resulting in heavy loss of marks. The student is therefore advised to get used to the naming system shown here.

(5) In some cases, DR lat is not given at all but then an indication of the Az at mer pass would be given. By using the above naming system, the answer is obtained easily and quickly.

(6) Whether 'd' correction is to be added or subtracted is known by inspecting the dec for the required hour and the next hour in the almanac. If dec is increasing, d correction is additive and vice versa.

EXERCISE - 5

(Latitude by meridian altitude SUN)

(1) On 21st Jan 1992, in DR 24° 36'S 110° 20'W, the sextant altitude of the Sun's LL on the meridian was 85° 05.5'. If IE was 1.6' off the arc and HE was 10m, find the latitude and state the direction of the PL (LOP).

(2) On 1st Sept 1992, DR equator 50° 27'E, the sextant meridian altitude of the Sun's UL was 82° 10.4'. If IE was 2.4' on the arc and HE was 17m, required the latitude and the PL (LOP).

(3) On 1st May 1992, in DR longitude 179° 58'E, the observed altitude of the Sun's LL on the meridian was 64° 35.9' South of the observer. If HE was 15m, find the latitude and the PL.

(4) On 14th Sept 1992, in DR longitude 116° 27'W, the sextant meridian altitude of the Sun's UL North of the observer was 70° 29.8'. If IE was 3.2' off the arc and HE was 12m, find the latitude and state the direction of the PL (LOP).

(5) On 1st Dec 1992, in DR 06° 35'N 64° 18'W, owing to a hazy horizon to the South, a back angle observation of the Sun's LL on the meridian was made and the sextant altitude was found to be 118° 11.8'. If HE was 14m, and IE was 2.4' on the arc, required the latitude and the direction of the PL .

(Note: Back angle altitude has been explained in Chapter 10).

-o0o-

14.2 Azimuth - Sun:-

On 13th Sept 1992, in DR 23° 21'S 47° 18'W, the observed azimuth of the Sun was 046° (C) when the chron showed 01h 08m 10s. If chron error was 02m 12s slow and Var (variation) was 3°W, find the Dev (deviation) of the compass.

	d	h	m	s		d	h	m	s
Chron		01	08	10	or		13	08	10
Error		(+)	02	12			(+)	02	12
GMT		01	10	22		13	13	10	22
LIT(W)	(-)	03	09	12		(-)	03	09	12
LMT		22	01	10		13	10	01	10

GMT 13d 13h 10m 22s

GHA	016° 03.4'	dec	03° 34.5'N
Incr	002° 35.5'	d (1.0)	(-) 00.2'
GHA	018° 38.9'	dec	03° 34.3'N
Long(W)	(-) 047° 18.0'	lat	23° 21.0'S
LHA	331° 20.9'		
From Nautical Tables		T Az	049.8° (T)
A	0.79 N	C Az	046.0° (C)
B	0.13 N	Error	3.8° E
C	0.92 N	Var	3.0° W
		Dev	6.8° E

Notes

(1) The actual procedure of entering ABC Tables is not explained here as this is done in the Nautical Tables themselves.

(2) Whilst using Norie's Tables: '**A**' is **normally** named **opposite to lat** (i.e., when LHA is between 270° & 090°) and same as lat in unusual cases (i.e., when LHA is between 090° & 270°). '**B**' is named the **same as declination**. For naming 'C': If A & B are of same name, add and retain name; if of contrary names, subtract and retain name of larger one. The Az is named as follows: The prefix N or S is the name of 'C'

whereas the suffix E or W is depends on the value of LHA. If LHA is between 0° and 180°, the body lies to the West and if it is between 180° and 360°, the body lies to the East.

(3) When the latitude is 00° 00.0', it may be named N or S.

(4) The calculation of deviation is a matter of elementary chart-work and is not explained here. However, many students get stumped as to whether variation is to be added or subtracted to compass error to obtain deviation. A simple solution:-

T Az	049.8° (T)
Var	3.0° W
M Az	052.8° (M)
C Az	046.0° (C)
Dev	6.8° E

Calculation of Azimuth by scientific calculator:

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

If LHA < 180°, P = LHA. If LHA > 180°, P = (360 - LHA). Naming of A, B and Azimuth is as stated before. **When P > 90°,** the **minus sign** obtained for the value **of A** is to be **ignored** as it is taken care of **by changing name of A** (see foregoing note 2).

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 23° 21.0'}}{\text{Tan 28° 39.1'}} = 0.7901031 \text{ N}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 03° 34.3'}}{\text{Sin 28° 39.1'}} = 0.1301780 \text{ N}$$

$$C = 0.9202811 \text{ N}$$

$$\text{Tan Az} = \frac{1}{\text{C (Cos 23° 21')}} = 1.1835568$$

Az = N 49.8° E

i.e., **049.8° (T)**

EXERCISE 6

(Azimuth - SUN)

(1) On 29th Nov 1992, AM at ship in DR 26° 27'N 130° 27'W, the azimuth of the Sun was 130°(C) when chron showed 05h 49m 20s. If chron error was 01m 31s fast and variation was 3°E, find the deviation for the ship's head.

(2) On 22nd Sept 1992, PM at ship in DR 18° 20'N 85° 40'E, the azimuth of the Sun was 265°(C) when chron showed 10h 03m 20s. If chron error was 06m 18s slow and variation was 2°E, calculate the deviation of the compass.

(3) On Jan 19th 1992, in DR 40° 16'S 175° 31'E, the azimuth of the Sun was 267°(C) at 1618 ship's time. If the ship's time difference was 11h 30m from GMT and variation was 2.3°E, find the deviation for the ship's head.

(4) On 30th April 1992, in DR 00° 00.0' 60° 12'W, the Sun bore 080°(C) when chron showed 10h 57m 43s. If chron error was 03m 09s slow and variation was 1°W, find the deviation of the compass.

(5) On 31st Aug 1992, in DR 10° 11'S 000° 00', the azimuth of the Sun was 282°(C) when chron showed 05h 10m 25s. If chron error was 00m 05s fast and variation was 3°E, find the deviation for the ship's head.

14.3 Amplitude - SUN:-

On 5th March 1992, in DR 32° 12'N 178° 16'E, the rising Sun bore 100°(C). If variation was 3°E, find the deviation of the compass.

From Almanac	d	h	m	s	dec	06°	08.0'S
LMT Sunrise	05	06	22		d (1.0)	(-)	00.5'
LIT (E)	(-)	11	53	04	dec	06°	07.5'S
GMT Sunrise	04	18	28	56	lat	32°	12.0'N

From Nautical Tables,	True amplitude	=	E7.2°S
	True azimuth	=	097.2° (T)
	Compass azimuth	=	100.0° (C)
	Compass error	=	2.8° W
	Variation	=	3.0° E
	Deviation	=	5.8° W

Notes

(1) LMT of sunrise or sunset from the almanac needs only be interpolated and taken in whole minutes of time.

(2) When entering Nautical Tables for true amplitude, great care must be taken during interpolation to ensure accurate results.

(3) The prefix of true amplitude is E if the body is rising and W if the body is setting. Its suffix is the same as that of declination.

(4) Amp E20°N means: Sun's bearing is 20° to N of E - 070°(T).
Similarly, True amplitude E10°S = True bearing of 100°
W15°N = True bearing of 285°
W9.5°S = True bearing of 260.5°

(5) Sometimes the time of observation of the amplitude is given in the problem. Then given time should be used for calculation. It is, however, necessary to remove any ambiguity of chron time as explained in Chapter 12.

(6) If the latitude is 00° 00', the value of the amplitude is equal to the value of the declination. Naming of the amplitude is done as usual. For example: If lat is 00° 00' and dec is 05° 11'S, the rising amplitude = E5.2°S i.e., 095.2°(T) and the setting amplitude = W5.2°S i.e., 264.8°(T).

(7) Amplitude can also be worked out by the formula:-

Sin amp = (Sin dec . Sec lat).

EXERCISE 7

(Amplitude - SUN)

(1) On 2nd Sept 1992, in DR 40° 28'N 64° 20'E, the rising Sun bore 090°(C). If variation was 5°W, find the deviation of the compass.

(2) On 1st May 1992, in DR 30° 06'N 179° 45'W, the setting Sun bore 285°(C). If variation was 2°W, find the deviation for the ship's head.

(3) Jan 20th 1992, in DR 54° 20'S 46° 27'W, the Sun set bearing 234°(C). If variation was 3°W, find the deviation of the compass.

(4) Nov 30th 1992, the Sun rose bearing 110°(C) in DR 49° 18'N 110° 12'E at 00h 10m 00s chron time. If chron error was 05m 10s slow and variation was 10°E, find the deviation of the compass.

(5) Sept 23rd 1992, the Sun rose bearing 094°(C) in DR 00° 00' 120° 27'W when chron showed 01h 54m. If chron error was 03m 12s fast and variation was 2.7°W, find the deviation for the ship's head.

14.4 Longitude by chronometer - SUN:-

On 29th Nov 1992 in DR 26° 27'N 130° 27'W, the sextant altitude of the Sun's UL East of the meridian was 28° 11.0' when chron (error 01m 31s fast) showed 05h 49m 20s. If HE was 10m and IE was 2.3' off the arc, calculate the direction of the PL and a position through which it passes.

	d	h	m	s		d	h	m	s
Chron		05	49	20	or		17	49	20
Error		(-)	01	31			(-)	01	31
GMT		05	47	49		29	17	47	49
LIT(W)	(-)	08	41	48		(-)	08	41	48
LMT		21	06	01		29	09	06	01

GMT 29d 17h 47m 49s

Solution by Nautical Tables:

Hav LHA = Sec L . Sec D [Hav ZD - Hav (L ~ D)]

GHA	077° 52.1'	Sext alt	28° 11.0'
Incr	011° 57.3'	IE (off)	(+) 02.3'
GHA	089° 49.4'	Obs alt	28° 13.3'
dec	21° 36.1'S	Dip (10m)	(-) 05.6'
d (0.4)	(+) 00.3'	App alt	28° 07.7'
dec	21° 36.4'S	Tot Corrn UL	(-) 17.8'
lat	26° 27.0'N	T alt	27° 49.9'
(L ~ D)	48° 03.4'	TZD	62° 10.1'

Nat Hav ZD	0.26656	Log Hav diff	9.00329
Nat Hav(L ~ D)	0.16580	Log Sec L	0.04802
Nat Hav diff	0.10076	Log Sec D	0.03164
(See note 1 below to obtain LHA) →		Log Hav LHA	9.08295

LHA	319° 16.8'	A	0.58 S
GHA	089° 49.4'	B	0.61 S
Obs long	130° 32.6'W	C	1.19 S
DR lat	26° 27.0'N	Az 136.7°(T)←	Az S 43.3° E

PL 046.7° - 226.7° through DR lat and Obs long. **Answer.**

Notes

(1) Before meridian passage, LHA will be between 180° and 360° - obtain LHA from the bottom of the Haversine Table. After meridian passage, LHA will be between 000° and 180° - obtain LHA from the top of the Haversine Table.

(2) Correction of altitudes has been explained in Chapters 9 & 10.

(3) To obtain (L ~ D), same names subtract, opposite names add.

(4) The answer must clearly state the direction of the PL and that it is to be drawn through DR lat and Obs long.

Solution by scientific calculator:

$$\text{Cos P} = \frac{\text{Sin T alt} \mp \text{Sin lat . Sin dec}}{\text{Cos lat . Cos dec}}$$

Note:- If Lat and dec are same name (-), contrary names (+). Hence in the formula, (-) has been put above the (+).

T alt = 27° 49.9' lat = 26° 27.0'N dec = 21° 36.4'S

$$\text{Cos P} = \frac{\text{Sin 27° 49.9'(+)Sin 26° 27.0'. Sin 21° 36.4'}}{\text{Cos 26° 27.0' . Cos 21° 36.4'}} = 0.757907$$

P = 40° 43.2'. Before mer pass so LHA = 360° - P = 319°16.8'

GHA = 089°49.4'

Obs long = 130°32.6'W

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

If LHA < 180°, P = LHA. If LHA > 180°, P = (360 - LHA). Naming of A, B and Azimuth is as stated before. **When P > 90°, the minus sign** obtained for the value **of A** is to be **ignored** as it is taken care of **by changing name of A** (see note 2, Chap. 14.2).

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan } 26° \ 27.0'}{\text{Tan } 40° \ 43.2'} = 0.5779801 \text{ S}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan } 21° \ 36.4'}{\text{Sin } 40° \ 43.2'} = 0.6071199 \text{ S}$$

$$C = 1.1851000 \text{ S}$$

$$\text{Tan Az} = \frac{1}{C \ (\text{Cos } 26° \ 27')} = 0.9424646$$

Az = S 43.3° E .
i.e., **136.7° (T)**

PL 046.7° - 226.7° through the DR lat and the Obs long. **Answer.**

EXERCISE 8

(Longitude by chron - SUN)

(1) On 31st Aug 1992, PM at ship in DR 10° 11'S 000° 00', the Sextant altitude of the Sun's LL was 39° 15' when the chron (error 01m 30s fast) showed 03h 11m 20s. If IE was 2.5' on the arc and HE was 17m, find the direction of the PL and a position through which to draw it.

(2) On 30th April 1992, in DR 00° 20'N 60° 12'W, the sextant altitude of the Sun's UL East of the meridian was 44° 13.4' when chron (error 03m 09s slow) showed 00h 57m 43s. If IE was 3.1' off the arc and HE was 20m, find the direction of the PL and the longitude where it crosses the DR lat.

(3) On 19th Jan 1992, at about 1530 at ship in DR 40° 16'S 175° 31'E, the sextant altitude of the Sun's LL was 43° 27.4' when the chron (error 02m 12s fast) showed 03h 50m 12s. If HE

was 22m and IE was 1.5' on the arc, required the direction of the PL and a position through which it passes.

(4) On 22nd Sept 1992, PM at ship in DR 48° 20'N 85° 40'E, the Sextant altitude of the Sun's UL was 20° 14.8' when the chron (error 06m 18s slow) showed 10h 03m 20s. If IE was 2.2' on the arc and HE was 25m, find the direction of the PL and a position through which it passes.

(5) On 5th March 1992, AM at ship in DR 38° 11'S 151° 10'E, the sextant altitude of the Sun's LL was 35° 59.1' when the chron showed 10h 54m 54s. The chron was 01m 20s slow at 12h GMT on 25th Feb 1992 and gaining 4s daily. If IE was 1.3' off the arc and HE was 30m, find the direction of the PL and a position through which it passes.

14.5 Intercept - SUN:-

On 29th Nov 1992 in DR 26° 27'N 130° 27'W, the sextant altitude of the Sun's UL East of the meridian was 28° 11', when the chron (error 01m 31s fast) showed 05h 49m 20s. If HE was 10m and IE was 2.3' off the arc, calculate the direction of the PL and a position through which it passes.

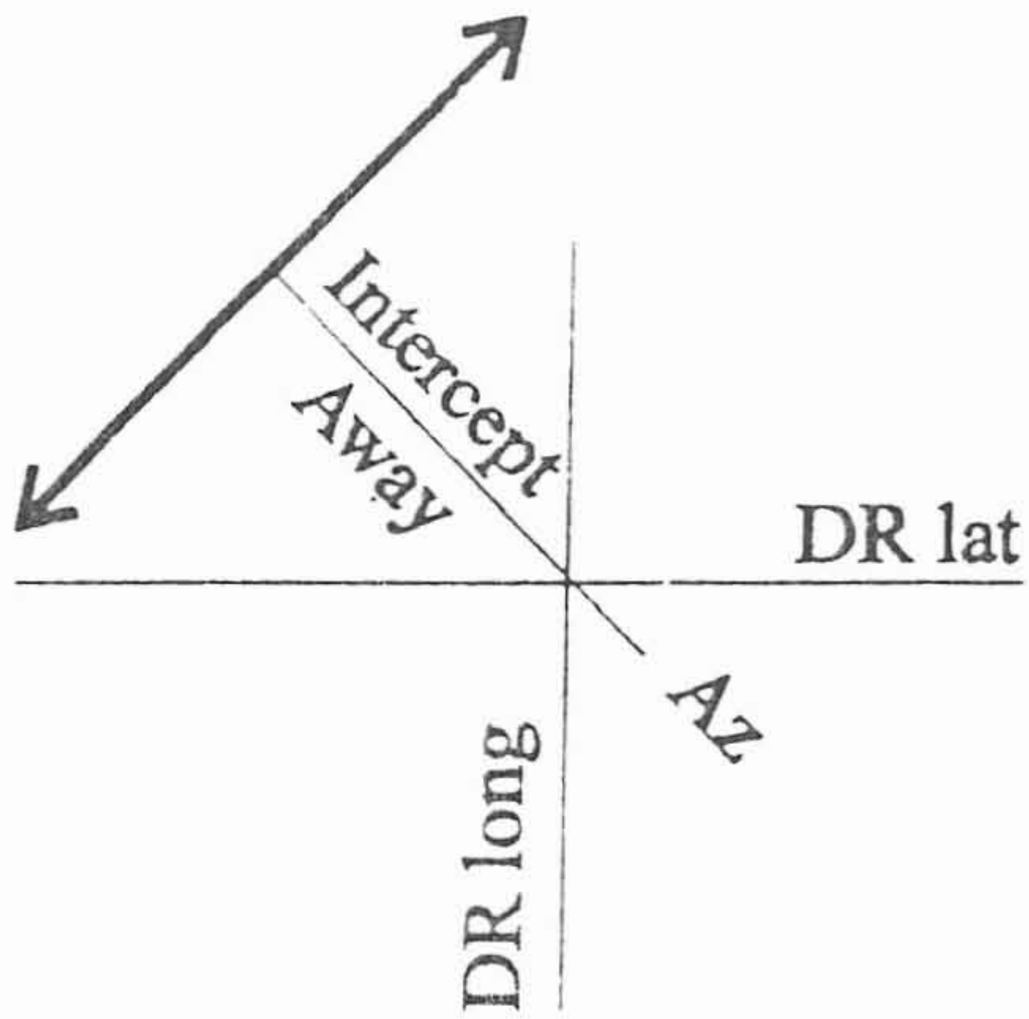
	d h m s		d h m s
Chron	05 49 20	or	17 49 20
Error	(-) 01 31		(-) 01 31
GMT	05 47 49		29 17 47 49
LIT(W)	(-) 08 41 48		(-) 08 41 48
LMT	21 06 01		29 09 06 01

GMT 29d 17h 47m 49s

Solution by Nautical Tables:

Hav CZD = (Hav LHA . Cos L . Cos D) + Hav (L ~ D)

GHA	077° 52.1'	Sext alt	28° 11.0'
Incr	011° 57.3'	IE (off)	(+) 02.3'
GHA	089° 49.4'	Obs alt	28° 13.3'
Long W	130° 27.0'	Dip (10m)	(-) 05.6'
LHA	319° 22.4'	App alt	28° 07.7'
dec	21° 36.1'S	Tot Corrn UL	(-) 17.8'
d (0.4)	(+) 00.3'	T alt	27° 49.9'
dec	21° 36.4'S	TZD	62° 10.1'
lat	26° 27.0'N	Log Hav LHA	9.08104
(L ~ D)	48° 03.4'	Log Cos L	9.95198
		Log Cos D	9.96836
		Log Hav sum	9.00138
		Nat Hav Sum	0.10032
		Nat Hav(L ~ D)	0.16580
		Nat Hav CZD	0.26612
		CZD	62° 06.7'
		TZD	62° 10.1'
		Int (AWAY)	03.4'
		DR lat	26° 27.0'N
		DR long	130° 27.0'W
		A 0.58S	**Az** S 43.3° E
		B 0.61S	i.e. 136.7°(T)
		C 1.19S	**PL** 046.7- 226.7



Notes

(1) A rough sketch (not necessarily to scale) should be drawn to show that the student knows where the PL is to be drawn.

(2) Calculation of the latitude and longitude of the ITP (intercept terminal point) is not necessary in such a problem.

Solution by scientific calculator

Cos CZD = Cos P . Cos lat . Cos dec ± Sin lat . Sin dec

Note:- If Lat and dec are same name (+), contrary names (-). Hence in the formula, the (+) has been put above the (-). The signs are opposite to that for long by chron formula.

If LHA lies between 0° and 180°, P = LHA
If LHA is between 180° & 360°, P = 360 - LHA

P = 40° 37.6' lat = 26° 27.0'N dec = 21° 36.4'S

Cos CZD = Cos 40° 37.6'. Cos 26° 27.0' . Cos 21° 36.4'
(-) Sin 26° 27.0' . Sin 21° 36.4'
= 0.4677575

CZD = 62° 06.7'
TZD = 62° 10.1'
Int (AWAY) = 3.4'

$A = \frac{\text{Tan lat}}{\text{Tan P}}$ $B = \frac{\text{Tan dec}}{\text{Sin P}}$ $\text{Tan Az} = \frac{1}{\text{C . Cos lat}}$

$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 26° 27.0'}}{\text{Tan 40° 37.6'}} = 0.5798880\ S$

$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 21° 36.4'}}{\text{Sin 40° 37.6'}} = 0.6082719\ S$

C = 1.1881599 S

$\text{Tan Az} = \frac{1}{\text{C (Cos 26° 27')}} = 0.9400374$ Az = S 43.2° E
i.e., 136.8° (T)

DR lat 26° 27.0'N DR long 130° 27.0'W Intercept 3.4' AWAY
Azimuth 136.8°(T) PL 046.8° - 226.8° **Answer.**

EXERCISE 9

(Intercept - SUN)

(1) On 5th March 1992, AM at ship in DR 38° 11'S 151° 10'E, the sextant altitude of the Sun's LL was 35° 59.1' when the chron showed 10h 54m 54s. The chron was 01m 20s slow at 12h GMT on 25th Feb 1992 and gaining 4s daily. If IE was 1.3' off the arc and HE was 30m, find the direction of the PL and a position through which it passes.

(2) On 22nd Sept 1992, PM at ship in DR 48° 20'N 85° 40'E, the Sextant altitude of the Sun's UL was 20° 14.8' when the chron (error 06m 18s slow) showed 10h 03m 20s. If IE was 2.2' on the arc and HE was 25m, find the direction of the PL and a position through which it passes.

(3) On 19th Jan 1992, at about 1530 at ship in DR 40° 16'S 175° 31'E, the sextant altitude of the Sun's LL was 43° 27.4' when the chron (error 02m 12s fast) showed 03h 50m 12s. If HE was 22m and IE was 1.5' on the arc, required the direction of the PL and a position through which it passes.

(4) On 30th April 1992, in DR 00° 20'N 60° 12'W, the sextant altitude of the Sun's UL East of the meridian was 44° 13.4' when chron (error 03m 09s slow) showed 00h 57m 43s. If IE was 3.1' off the arc and HE was 20m, find the intercept and the direction of the PL.

(5) On 31st Aug 1992, PM at ship in DR 10° 11'S 000° 00', the sextant altitude of the Sun's LL was 39° 15' when the chron (error 01m 30s fast) showed 03h 11m 20s. If IE was 2.5' on the arc and HE was 17m, find the direction of the PL and a position through which to draw it.

14.6 Ex-meridian - SUN:-

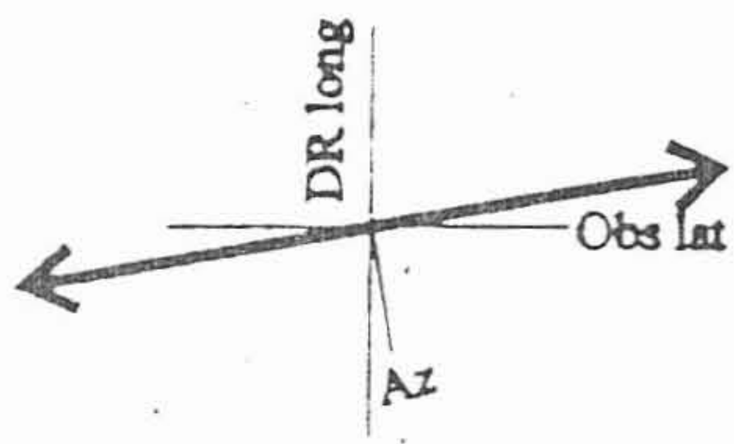
On 4th March 1992, DR 27° 18'N 168° 11'W, the sextant altitude of the Sun's LL near the meridian was 56° 19.8' when the chron showed 11h 13m 24s. If chron error was 01m 20s slow, HE was 12m and IE was 2.8' on the arc, find the direction of the PL and a position through which it passes. **Note:** Near the meridian means that working is to be by the ex-meridian method.

	d	h	m	s		d	h	m	s
Chron		11	13	24	or		23	13	24
Error		(+)	01	20			(+)	01	20
GMT		11	14	44		04	23	14	44
LIT(W)	(-)	11	12	44		(-)	11	12	44
LMT		00	02	00		04	12	02	00

GMT 04d 23h 14m 44s

Solution by Nautical Tables:

GHA	162° 06.4'	Sext alt	56° 19.8'
Incr	003° 41.0'	IE (on)	(-) 02.8'
GHA	165° 47.4'	Obs alt	56° 17.0'
Long W	168° 11.0'	Dip (12m)	(-) 06.1'
LHA	357° 36.4'	App alt	56° 10.9'
dec	06° 03.2'S	Tot Corrn LL	(+) 15.6'
d (1.0)	(-) 00.2'	T alt	56° 26.5'S
dec	06° 03.0'S	TZD	33° 33.5'N
		Reduction	(-) 04.9'*
		MZD	33° 28.6'N
		dec	06° 03.0'S
		Obs lat	27° 25.6'N
		DR long	168° 11.0'W
		PL	085.7°- 265.7°



A 12.40S
B 02.53S
C 14.93S
Az S4.3°E
i.e., 175.7° (T)

*** Working steps to obtain Reduction from Nautical Tables:-**

From Table I - value F (Burton's) or value A (Norie's) = 3.20

From Table II, First Correction	=	4.9'
From Table III, Second Correction	= (-)	0.0'
Reduction to the TZD observed	=	4.9'

Notes:

(1) In this problem, no hint of ship's time is given but it is noticed the possibilities of LMT are 00h or 12h. Since mer pass of Sun must be close to 12h only, 00h is impossible.

(2) By entering ex-meridian table I with lat and dec, we get A (Norie's Tables) or F (Burton's Tables). There are separate tables for lat & dec having same name and contrary names.

(3) By entering ex-meridian table II with LHA and A (or F), we get the First Correction which is in minutes of arc.

(4) By entering ex-meridian Table III with first correction and true alt, we get the Second Correction.

(5) Second Correction is always subtracted from First Correction to get the Reduction (or R) in minutes of arc.

(6) The value of R is to be subtracted from TZD to get MZD.

(7) Some books say 'Add reduction to true altitude to get meridian alt. Then subtract 90° to get MZD'. Though this is mathematically correct, this method cannot be practically reasoned and explained to the student. Reduction should reduce something, not increase. Also, the student can easily remember that, except for Polaris, sextant altitude should be converted into TZD in all problems in Practical Navigation.

(8) Ex-meridian table IV is not actually used in working the problem. It is used only to ascertain the ex-meridian limits (EML) as explained in Chapter 13 (4).

(9) Whether MZD and dec are to be added or subtracted, to obtain Obs lat, is decided by naming the true alt and MZD as explained earlier in this Chapter under 'Lat by mer alt - Sun'.

(10) MZD can also be obtained by the Haversine formula:-
Hav MZD = Hav TZD - (Hav LHA . Cos L . Cos D).

Solution by scientific calculator:-

Cos MZD = Cos TZD + [(1 - Cos P) . Cos DR lat . Cos dec]

Note: TZD 33° 33.5', P 2° 23.6', DR lat 27° 18'N, dec 06° 03'S

= Cos 33°33.5' + [(1- Cos 2°23.6') . Cos 27°18' . Cos 06°03']

= 0.8340942. Hence MZD, by scientific calculator, = 33° 28.7'

MZD	=	33° 28.7' N	A = Tan lat / Tan P =	12.3490340 S
dec	=	06° 03.0' S		
Obs lat	=	27° 25.7' N	B = Tan dec / Sin P =	02.5380303 S
DR long	=	168° 11' W		
			C =	14.8870640 S

Tan Az = 1 / (C . Cos lat) = 0.075592 Az = S04.3°E = 175.7° (T)

PL = 085.7° - 265.7°

-o0o-

Exercise 10

(Ex-meridian altitude - SUN)

(1) On 1st Sept 1992, in DR 23° 18'N 165° 02'E, the sextant altitude of the Sun's UL near the meridian was 75° 01.7' when chron (error 03m 21s slow) showed 00h 45m 51s. If IE was 3.2' off the arc and HE was 20m, find the direction of the PL and a position through which it passes.

(2) On 2nd May 1992, in DR 15° 36'S 080° 11'W, the sextant altitude of the Sun's LL near the meridian was 58° 25.6' when chron (error 02m 18s fast) showed 05h 40m 06s. If IE was 1.6' on the arc and HE was 15m, find the direction of the PL and the lat where it cuts the DR long.

(3) On 6th March 1992, in EP 52° 12'N 170° 40'E, the sextant altitude of the Sun's UL near the meridian was 31° 59.8' when chron (error 01m 50s fast) showed 01h 29m 20s. If IE was 2.3' on the arc and HE was 40m, find the direction of the PL and a position through which to draw it.

(4) On 21st Jan 1992, in DR 00° 00' 97° 48'W, the sextant altitude of the Sun's LL near the meridian was 69° 28.7' when chron (error 12m 05s slow) showed 06h 13m 27s. If IE was 2.0' off the arc and HE was 12m, find the direction of the PL and a position through which it passes.

(5) On 23rd Sept 1992, in EP 48° 20'S 158° 46'E, the sextant altitude of the Sun's LL near the meridian was 41° 36.7' at 01h 11m 16s chron time. If chron error was 11m 04s fast, IE was 3.4' on the arc and HE was 17m, find the direction of the PL and the lat where it cuts the DR long.

15

WORKED EXAMPLES

AND EXERCISES - STARS

15.1 Latitude by meridian altitude - STAR:-

On 1st Dec 1992, AM at ship in DR 45° 20'S 75°00'E, the sextant meridian altitude of the star PROCYON was 39° 28.8'. If IE was 1.5' off the arc and HE was 25m, find the latitude and the PL.

Sext Alt	39° 28.8'	
IE (off)	(+) 01.5'	
Obs alt	39° 30.3'	
Dip (25m)	(-) 08.8'	
App alt	39° 21.5'	
Tot corm	(-) 01.2'	
T alt	39° 20.3' N	→ (Named same as azimuth)
MZD	50° 39.7' S	→ (Named opposite to T alt)
Dec	05° 14.6' N	→ (Contrary names subtract)
Latitude	45° 25.1' S	PL :- E - W

Sometimes, the question also says 'State the GMT of meridian passage'. In such a case, proceed as follows:-

GHA ★ + E (or - W) long = LHA ★

Note GHA ★ = GHA γ + SHA ★. At mer pass ★, LHA★ = 360°
SHA ★ is obtained from that day's page in the almanac.

Hence at mer pass ★, GHA γ + SHA ★ + E (or - W) long = 360°

GHA γ + 245° 15.5' + 75° 00' = 360° or GHA γ = 039°44.5'
From almanac, for GMT December 01d 21h GHA γ = 025°57.9'
54m 57s ← Increment ← 013°46.6'

Note: In referring to the almanac, it has been assumed that the date of GMT would be the same as that of ship i.e., 1st December. However, it may be possible that the date of GMT may be one day earlier or later than that assumed. It is therefore necessary to check up by applying LIT to the assumed GMT, as shown below, and alterations made, if necessary, to the GMT date and time.

GMT mer pass: Dec	01d	21h	54m	57s	
LIT (E)	(+)	05	00	00	
LMT	02	02	54	57	But reqd date is 1st Dec
	(-)	23	56	04	(one sidereal day)*
Correct LMT	01	02	58	53	
LIT (E)	(-)	05	00	00	
Correct GMT Nov	30	21	58	53	**Answer.**

* The time interval between any two successive meridian passages of γ is one sidereal day which is equal to 23h 56m 04s. Hence one sidereal day may be added or subtracted as appropriate to ensure that the meridian passage is correct for ship's date.

EXERCISE - 11

(Latitude by meridian altitude - STARS)

(1) On 4th March 1992, in DR 45° 10'N 120° 30'W, the sextant meridian altitude of the star ANTARES was 18° 26.2'. If IE was 3.2' off the arc and HE was 10m, find the latitude and state the direction of the PL (LOP).

(2) On 12th Sept 1992, DR 43° 05'S 72° 20'E, the sextant meridian altitude of the star ALDEBARAN was 30° 40.2'. If IE was nil and HE was 18m, required the latitude and PL (LOP) and state the GMT of meridian passage.

(3) On 22nd Sept 1992, in DR longitude 90° 06'E, the observed altitude of the star RIGEL on the meridian was 73° 24.2' North of the observer. If HE was 15m, find the latitude and the PL. State the LMT of meridian passage.

(4) On 20th Jan 1992, in DR 57° 31'N 164° 20'W, the sextant meridian altitude of the star DIPHDA was 14° 33.7'. If IE was 0.6' on the arc and HE was 14.5m, find the latitude and the direction of the PL. State the GMT of meridian passage.

(5) On 1st May 1992, in DR 30° 18'N 135° 02'W, a back angle sextant meridian altitude of the star REGULUS was 108° 16.5'. If HE was 14m, and IE was 2.4' on the arc, required: the GMT of mer pass, the latitude and the direction of the PL.

15.2 Azimuth - STAR:-

On 21st Sept 1992, PM at ship in DR 43° 18'S 140° 11'W, the star CANOPUS bore 150° (C) at 07h 28m 52s chron time (error 02m 12s slow). If Var was 3°E, find dev of compass.

	d	h	m	s		d	h	m	s
Chron		07	28	52	or		19	28	52
Error		(+)	02	12			(+)	02	12
GMT	22	07	31	04			19	31	04
LIT(W)	(-)	09	20	44		(-)	09	20	44
LMT	21	22	10	20			10	10	20

GMT 22d 07h 31m 04s

GHA γ		106° 23.7'	**From Nautical Tables**				
Incr		007° 47.3'	A	0.58 S			
GHA γ		114° 11.0'	B	1.55 S			
Long(W)	(-)	140° 11.0'	C	2.13 S		Alternative	
LHA γ		334° 00.0'	T Az	147.2° (T)	T Az	147.2°	(T)
SHA ★		264° 03.1'	C Az	150.0° (C)	Var	3.0°	E
LHA ★		238° 03.1'	Error	2.8° W	M Az	144.2°	M
dec		52° 41.2'S	Var	3.0° E	C Az	150.0°	(C)
lat		43° 18.0'S	Dev	5.8° W	Dev	5.8°	W

Note: Working is very similar to that of azimuth - Sun except that GHA γ and SHA★ have been used (see Chapters 2 & 4.6). When looking up GHA γ and its increment care must be taken to consult the γ columns and not those of the Sun.

Calculation of Azimuth by scientific calculator:

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

If LHA < 180°, P = LHA. If LHA > 180°, P = (360 - LHA). Naming of A, B and Azimuth is as stated under Az Sun (Chapter 14.2). **When P > 90°,** the **minus sign** obtained for the value of A is to be **ignored** as it is taken care of **by changing name of A** (see note 2 under Chapter 14.2).

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan } 43° \ 18.0'}{\text{Tan } 121° \ 56.9'} = 0.5876661 \text{ S}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan } 52° \ 41.2'}{\text{Sin } 121° \ 56.9'} = 1.5462752 \text{ S}$$

$$C = 2.1339413 \text{ S}$$

$$\text{Tan Az} = \frac{1}{C \ (\text{Cos } 43° \ 18')} = 0.6439049$$

Az = S 32.8° E
i.e., **147.2° (T)**

EXERCISE 12

(Azimuth - STARS)

(1) On 6th March 1992, AM at ship in DR 24° 12'S 83° 46'E, the azimuth of the star ALTAIR was 078°(C) at 10h 38m 40s chron time. If chron error was 03m 24s fast and variation was 3°W, find the deviation for the ship's head.

(2) On 30th Nov 1992, PM at ship in DR 48° 57'N 173° 18'W, the azimuth of the star VEGA was 296°(C) at 07h 27m 12s chron time. If chron error was 12m 10s slow and variation was 3°W, calculate the deviation of the compass.

(3) On 1st May 1992, AM at ship in DR 62° 11'S 179° 58'E, the azimuth of the star SPICA was 312°(C) at 01h 03m 16s chron time (error 03m 08s fast). If variation was 10°E, find the deviation for the ship's head.

(4) On 13th Sept 1992, in DR 30° 46'N 90° 36'W, the star RASALHAGUE bore 275°(C) at 04h 36m GMT. If variation was 5°W, find the deviation of the compass.
(Caution: Date given is ship's date not GMT date).

(5) On 21st Jan 1992, at 0320 ship's time, in DR 64° 12'N 112° 18'E, the star DENEB bore 034.5°(C). If variation was 4°E, and ship's time was 7h ahead of GMT, find the deviation.

15.3 Longitude by chronometer - STAR:-

On 23rd Aug 1992 PM at ship in DR 34° 31'S 03° 30'W, the sextant altitude of the star SPICA was 45° 27.2' when chron (error 02m 19s slow) showed 06h 15m 00s. If HE was 11m and IE was 2.1' on the arc, calculate the direction of the PL and a position through which it passes.

	d	h	m	s		d	h	m	s
Chron		06	15	00	or		18	15	00
Error		(+)	02	19			(+)	02	19
GMT		06	17	19		23	18	17	19
LIT(W)	(-)	00	40	00		(-)	00	40	00
LMT		05	37	19		23	17	37	19

GMT 23d 18h 17m 19s

Solution by Nautical Tables:

Hav LHA = Sec L . Sec D [Hav ZD - Hav (L ~ D)]

GHA γ	242° 16.6'	Sext alt	45° 27.2'
Incr	004° 20.5'	IE (on)	(-) 02.1'
GHA γ	246° 37.1'	Obs alt	45° 25.1'
SHA ★	158° 47.8'	Dip (11m)	(-) 05.8'
GHA ★	045° 24.9'	App alt	45° 19.3'
dec	11° 07.4'S	Tot Corrn	(-) 01.0'
lat	34° 31.0'S	T alt	45° 18.3'
(L ~ D)	23° 23.6'	TZD	44° 41.7'

Nat Hav ZD	0.14457	Log Hav diff	9.01479
Nat Hav(L ~ D)	0.04110	Log Sec L	0.08409
Nat Hav diff	0.10347	Log Sec D	0.00824
(See note 1 below to obtain LHA) →		Log Hav LHA	9.10712

LHA ★	041° 55.4'	A	0.76 N
GHA ★	045° 24.9'	B	0.29 S
Obs long	003° 29.5'W	C	0.47 N
DR lat	34° 31.0'S	Az 291.2° (T)←Az N 68.8° W	

PL 021.2° - 201.2° through DR lat and Obs long. **Answer.**

Notes

(1) When converting Log Hav LHA into calculated LHA ★ a small doubt arises whether LHA should be a small number or a large one i.e., 041° or 319° in this problem. This doubt is removed by applying DR long to GHA ★ and getting approximate LHA ★. The calculated LHA will be very close to the approximate LHA.

(2) Working is similar to long by chron Sun except that GHA γ and SHA ★ are to be used.

(3) For entering ABC Tables, use the calculated LHA.

(4) The answer must clearly state the direction of the PL and that it is to be drawn through DR lat and Obs long.

Solution by scientific calculator:

$$\text{Cos P} = \frac{\text{Sin T alt} \mp \text{Sin lat . Sin dec}}{\text{Cos lat . Cos dec}}$$

Note:- If Lat and dec are same name (-), contrary names (+). Hence in the formula, (-) has been put above the (+). Entire numerator is Sin and entire denominator is Cos.

T alt = 45° 18.3' lat = 34° 31.0'S dec = 11° 07.4'S

$$\text{Cos P} = \frac{\text{Sin } 45° \ 18.3' (-) \text{Sin } 34° \ 31.0' . \text{ Sin } 11° \ 07.4'}{\text{Cos } 34° \ 31.0' \ . \text{ Cos } 11° \ 07.4'} = 0.744039$$

P = 41° 55.4' (See foregoing note no:1) LHA = P = 041°55.4'

GHA = 045°24.9'

Obs long = 003°29.5'W

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

If LHA < 180°, P = LHA. If LHA > 180°, P = (360 - LHA). Naming of A, B and Azimuth is as stated before. **When P > 90°,** the **minus sign** obtained for the value **of A** is to be **ignored** as it is taken care of **by changing name of A** (see note 2, Chap. 14.2).

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan } 34° \ 31.0'}{\text{Tan } 41° \ 55.4'} = 0.7658369 \text{ N}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan } 11° \ 07.4'}{\text{Sin } 41° \ 55.4'} = 0.2942743 \text{ S}$$

C = 0.4715626 N

$$\text{Tan Az} = \frac{1}{\text{C (Cos } 34° \ 31')} = 2.5736755$$

Az = N 68.8° W

i.e., 291.2° (T)

EXERCISE 13

(Longitude by chron - STAR)

(1) On 29th Nov 1992, AM at ship in DR 25° 30'S 107° 20'W, the sextant altitude of the star RIGEL was 35° 10.3' when the chron (error 02m 50s fast) showed 11h 32m 10s. If IE was 2.8' on the arc and HE was 12m, find the direction of the PL and a position through which to draw it.

(2) On 22nd Sept 1992, PM at ship in DR 60° 10'N 92° 27'E, the sextant altitude of the star ARCTURUS was 25° 01' when chron (error 05m 01s slow) showed 00h 46m 31s. If IE was 0.2' on the arc and HE was 17m, find the direction of the PL and the longitude where it crosses the DR lat.

(3) On 19th Jan 1992, at about 1900 at ship in DR 00° 02'N 170° 50'E, the sextant altitude of the star BETELGEUSE was 43° 11.1' when the chron (error 01m 18s fast) showed 07h 35m 02s. If HE was 18m and IE was 1.3' off the arc, required the direction of the PL and a position through which it passes.

(4) On 30th April 1992, PM at ship in DR 34° 18'S 40° 20'W, the observed altitude of the star SIRIUS was 57° 50.7' at 08h 51m 38s chron time. The chron error was 00m 10s slow at 12 GMT on 22nd April and its daily rate was 3s gaining. If HE was 21m, find the direction of the PL and a position through which it passes.

(5) On 31st Aug 1992, AM at ship in DR 40° 30'N 64° 56'E, the sextant altitude of the star DIPHDA was 21° 23.4' when the chron (error nil) showed 00h 20m 26s. If IE was 0.9' off the arc and HE was 9m, find the direction of the PL and a position through which it passes.

15.4 Intercept - STAR:-

On 23rd Aug 1992 in DR 34° 31'S 003° 30'W, at about 1800 hours at ship, the sextant altitude of the star SPICA was 45° 27.2', when the chron (error 02m 19s slow) showed 06h 15m 00s. If HE was 11m and IE was 2.1' on the arc, calculate the direction of the PL and a position through which it passes.

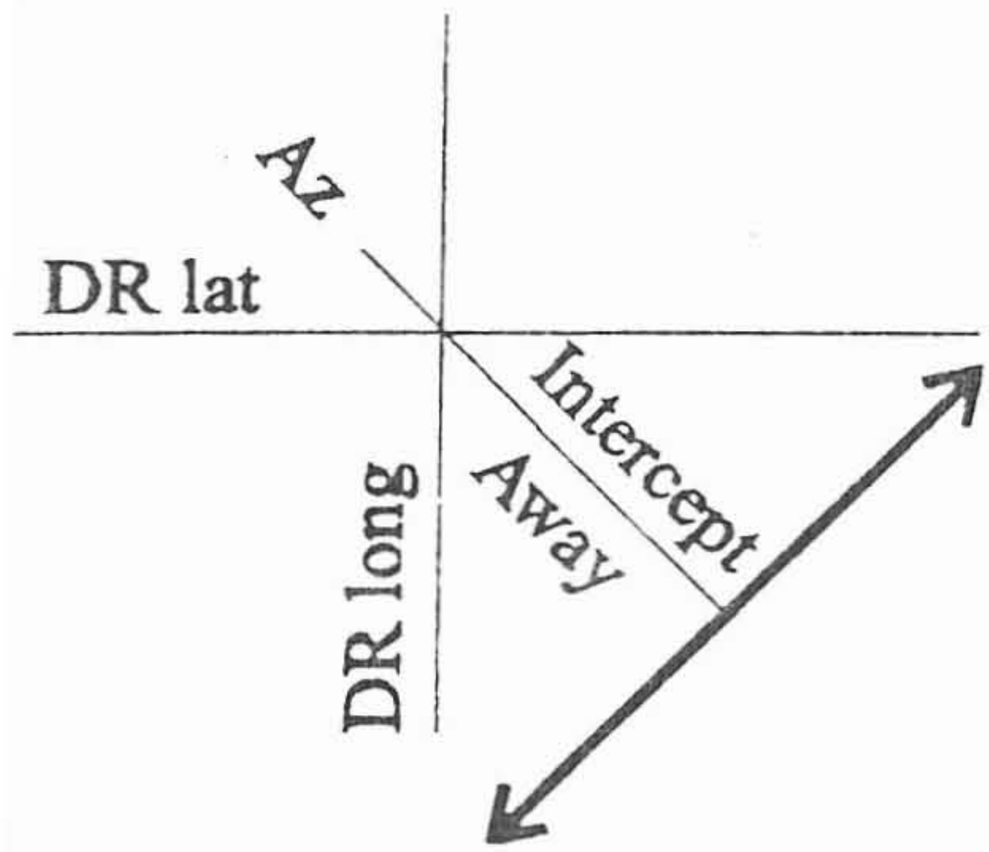
	d	h	m	s		d	h	m	s
Chron		06	15	00	or		18	15	00
Error		(+)	02	19			(+)	02	19
GMT		06	17	19		23	18	17	19
LIT(W)	(-)	00	14	00		(-)	00	14	00
LMT		06	03	19		23	18	03	19

GMT 23d 18h 17m 19s

Solution by Nautical Tables:

Hav CZD = (Hav LHA . Cos L . Cos D) + Hav (L ~ D)

GHA γ	242° 16.6'	Sext alt	45° 27.2'
Incr	004° 20.5'	IE (on)	(-) 02.1'
GHA γ	246° 37.1'	Obs alt	45° 25.1'
Long W	003° 30.0'W	Dip (11m)	(-) 05.8'
LHA γ	243° 07.1'	App alt	45° 19.3'
SHA ★	158° 47.8'	Tot Corrn	(-) 01.0'
LHA ★	041° 54.9'	T alt	45° 18.3'
		TZD	44° 41.7'
		Log Hav LHA	9.10698
dec	11° 07.4'S	Log Cos L	9.91591
lat	34° 31.0'S	Log Cos D	9.99176
(L ~ D)	23° 23.6'	Log Hav sum	9.01465



Nat Hav Sum	0.10343
Nat Hav(L ~ D)	0.04110
Nat Hav CZD	0.14453
CZD	44° 41.3'
TZD	44° 41.7'
Int (AWAY)	00.4'
DR lat	34° 31.0' S
DR long	03° 30.0'W
A 0.76N	
B 0.29S	**Az** N 68.8° W

C 0.47N i.e. 291.2° (T)

PL 021.2° - 201.2° (T)

Notes

(1) A rough sketch (not necessarily to scale) should be drawn to show that the student knows where the PL is to be drawn.

(2) Calculation of the latitude and longitude of the ITP (intercept terminal point) is not necessary in such a problem.

Solution by scientific calculator

Cos CZD = Cos P . Cos lat . Cos dec ± Sin lat . Sin dec

Note:- If Lat and dec are same name (+), contrary names (-). Hence in the formula, the (+) has been put above the (-). The signs are opposite to that for long by chron formula. If LHA < 180°, P = LHA & if > 180°, P = (360 - LHA).

P = 41° 54.9' lat = 34° 31.0'S dec = 11° 07.4'S

Cos CZD = Cos 41° 54.9'. Cos 34° 31.0' . Cos 11° 07.4'
(+) Sin 34° 31.0' . Sin 11° 07.4'
= 0.7109397

CZD = 44° 41.3'
TZD = 44° 41.7'
Int (AWAY) = 0.4'

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan } 34° \ 31.0'}{\text{Tan } 41° \ 54.9'} = 0.7660610 \text{ N}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan } 11° \ 07.4'}{\text{Sin } 41° \ 54.9'} = 0.2943219 \text{ S}$$

$$C = 0.4717391 \text{ N}$$

$$\text{Tan Az} = \frac{1}{\text{C (Cos } 34° \ 31')} = 2.5727125$$

Az = N 68.8° W
i.e., 291.2° (T)

DR lat 34° 31.0'S DR long 003° 30.0'W Intercept 0.4' AWAY
Azimuth 291.2°(T) PL 021.2° - 201.2° (T) **Answer.**

EXERCISE 14

(Intercept - STARS)

(1) On 30th April 1992, PM at ship in DR 34° 18'S 40° 20'W, the observed altitude of the star SIRIUS was 57° 50.7' at 08h 52m 05s chron time. The chron error was 01m 40s fast at 06 GMT on 16th April and its daily rate was 4s losing. If HE was 21m, find the direction of the PL and a position through which it passes.

(2) On 19th Jan 1992, at about 1900 at ship in DR 00° 02'N 170° 50'E, the sextant altitude of the star BETELGEUSE was 43° 11.1' when the chron (error 01m 18s fast) showed 07h 35m 02s. If HE was 18m and IE was 1.3' off the arc, required the direction of the PL and a position through which it passes.

(3) On 29th Nov 1992, AM at ship in DR 25° 30'S 107° 20'W, the sextant altitude of the star RIGEL was 35° 10.3' when the chron (error 02m 50s fast) showed 11h 32m 10s. If IE was 2.8' on the arc and HE was 12m, find the direction of the PL and a position through which to draw it.

(4) On 31st Aug 1992, AM at ship in DR 40° 30'N 64° 56'E, the sextant altitude of the star DIPHDA was 21° 23.4' when the chron (error 01m 06s fast) showed 00h 21m 32s. If IE was 0.9' off the arc and HE was 9m, find the direction of the PL and a position through which it passes.

(5) On 22nd Sept 1992, PM at ship in DR 60° 10'N 92° 27'E, the sextant altitude of the star ARCTURUS was 25° 01' when chron (error 05m 01s slow) showed 00h 46m 31s. If IE was 0.2' on the arc and HE was 17m, find the direction of the PL and the longitude where it crosses the DR lat.

15.5 Ex-meridian - STAR:-

On 2nd March 1992, PM at ship in DR 16° 12'N 92° 10'E, the sextant altitude of the star CAPELLA near the meridian was 60° 29.4' at 00h 30m 12s chron time (error 02m 06s slow). If HE was 48m and IE was 2.0' off the arc, find the direction of the PL and a position through which it passes. **Note:** Near the meridian means that working is to be by the ex-meridian method.

	d	h	m	s		d	h	m	s
Chron		00	30	12	or		12	30	12
Error		(+)	02	06			(+)	02	06
GMT		00	32	18		02	12	32	18
LIT(E)		(+) 06	08	40			(+) 06	08	40
LMT		06	40	58		02	18	40	58

GMT 02d 12h 32m 18s

Solution by Nautical Tables:

GHA γ	340° 31.7'	Sext alt	60° 29.4'
Incr	008° 05.8'	IE (off)	(+) 02.0'
GHA γ	348° 37.5'	Obs alt	60° 31.4'
Long E	092° 10.0'	Dip (48m)	(-) 12.2'
LHA γ	080° 47.5'	App alt	60° 19.2'
SHA ★	280° 57.9'	Tot Corrn	(-) 00.6'
LHA ★	001° 45.4'	T alt	60° 18.6' N
dec	45° 59.6'N	TZD	29° 41.4' S
		Reduction	(-) 2.1
A 09.56S		MZD	29° 39.3' S
B 33.77N		dec	45° 59.6' N
C 24.21N		**Obs lat**	16° 20.3' N
Az N2.5°W		**DR long**	92° 10.0' E
i.e., 357.5° (T)		**PL**	087.5°- 267.5°

*** Working steps to obtain Reduction from Nautical Tables:-**

From Table I - value F (Burton's) or value A (Norie's) = 2.63

From Table II, First Correction	=	2.1'
From Table III, Second Correction	=	(-) 0.0'
Reduction to the TZD observed	=	2.1'

Notes

(1) Working is similar to Ex-meridian altitude Sun (Chapter 14.6) except that GHA γ and SHA ★ have to be used.

(2) Ex-meridian star can also be worked by the Haversine formula as mentioned in Chapter 14.6 (note: 10).

[15 - STARS]

Solution by scientific calculator:-

Cos MZD = Cos TZD + [(1 - Cos P) . Cos DR lat . Cos dec]

Note: TZD 29° 41.4', P 1° 45.4', lat 16° 12'N, dec 45° 59.6'N

= Cos 29°41.4' + [(1- Cos 1°45.4').Cos 16°12'.Cos 45°59.6']

= 0.8690315. Hence MZD, by scientific calculator, = 29° 39.2'

MZD	=	29° 39.2' S	A = Tan lat / Tan P	=	09.5593685 S
dec	=	45° 59.6' N			
Obs lat	=	16° 20.4' N	B = Tan dec / Sin P	=	33.7724840 N
DR long	=	92° 10.0' E			---
			C	=	24.2131155 N

Tan Az = 1 / (C . Cos lat) = 0.043038 Az = N02.5°W = 357.5° (T)

PL = 087.5° - 267.5°

Exercise 15

(Ex-meridian altitude - STARS)

(1) On 12th Sept 1992, AM at ship in DR 00° 30'S 160° 20'W, the sextant altitude of the star ALDEBARAN near the meridian was 73° 09.5' at 03h 59m 29s chron time (error 05m 03s fast). If IE was 1.2' on the arc and HE was 9m, find the direction of the PL and a position through which it passes.

(2) On 2nd May 1992, PM at ship in DR 44° 11'S 102° 40'E, the sextant altitude of the star POLLUX near the meridian was 17° 14.6' at 10h 52m 08s chron time (error 02m 12s slow). If IE was 3.6' off the arc and HE was 12m, find the direction of the PL and the latitude where it cuts the DR longitude.

(3) On 20th Jan 1992, during morning twilight in DR 44° 07'N 64° 47'E, the sextant altitude of the star ARCTURUS near the meridian was 64° 58.8' at 02h 04m 54s by chron (error 10m 58s slow). IE 3.1' off the arc; HE 18m. Find the direction of the PL and a position through which to draw it.

(4) On 5th March 1992, at about 1835 hours at ship in DR 66° 40'N 86° 50'W, the sextant altitude of the star BETELGEUSE near the meridian was 30° 35.2' when chron (error 18m 04s fast) showed 00h 40m 30s. If IE was 0.7' off the arc and HE was 14m, find the direction of the PL and a position through which it passes.

(5) On 21st Sept 1992, AM at ship in DR 20° 50'S 62° 30'E, the observed altitude of the star CAPELLA near the meridian was 23° 07.1' at 01h 15m 06s chron time. If chron error was 00m 04s slow and HE was 10m, find the direction of the PL and the lat where it cuts the DR long.

15.6 Observation of Polaris:-

On 1st Sept 1992, AM at ship in DR 18° 00'N 178° 11'E, the sextant altitude of the Pole star was 18° 47.4' at 05h 21m 08s by chronometer (error 01m 18s slow). HE = 12.5m. IE = 1.6' on the arc. Find the direction of the PL and a position through which to draw it. If the azimuth was 001° (C), and var was 1.3° E, find the deviation.

	d	h	m	s			d	h	m	s
Chron		05	21	08		or		17	21	08
Error		(+)	01	18				(+)	01	18
GMT		05	22	26			Aug 31	17	22	26
LIT(E)		(+) 11	52	44				(+) 11	52	44
LMT		17	15	10			Sep 01	05	15	10

GMT 31d 17h 22m 26s

Sext alt	18°	47.4'	GHA γ	235° 07.3'
IE (on)	(-)	01.6'	Incr	005° 37.4'
Obs alt	18°	45.8'	GHA γ	240° 44.7'
Dip (12.5m)	(-)	06.2'	Long E	178° 11.0'
App alt	18°	39.6'	LHA γ	058° 55.7'
Tot Corm	(-)	02.8'		
T alt	18°	36.8'	True Az	359.7° (T)
a_0	00°	16.5'	Comp Az	001.0° (C)
a_1	00°	00.6'	Comp Err	1.3° (W)
a_2	00°	00.3'	Variation	1.3° (E)
Sum	18°	54.2'	**Deviation**	2.6° (W)
	(-) 1°			
Obs lat	17°	54.2'N		
DR long	178°	11.0'E		
PL	089.7°- 269.7°			

NOTES

(1) Values of a_0, a_1 and a_2 are obtained from the Pole Star Tables given in the Nautical Almanac.

(2) The latitude obtained by an observation of Polaris will be the correct latitude ONLY if the PL is exactly E - W. If not, the latitude obtained will be the latitude where the PL cuts the DR longitude, as in the foregoing worked example.

(3) Sometimes, the DR lat is not given in the question. For the purpose of obtaining a_1 correction, the true altitude may be used, in place of DR latitude, to enter the table.

(4) The latitude obtained by an observation of Polaris must necessarily be N because the Pole Star is not visible from the Southern Hemisphere.

-o0o-

Exercise 16

(Altitude and Azimuth - POLARIS)

(1) On the morning of 1st Dec 1992, in DR 47° 16'N 143° 26'E, the sextant altitude of the Polestar was 46° 50.7' at 08h 51m 15s chron time (error 05m 11s slow). If IE was 2.1' off the arc and HE was 17m, find the direction of the PL and a position through which it passes.

(2) In the evening of 22nd Sept 1992, a ship in DR long 160° 12'W, found the sextant altitude of Polaris to be 36° 18.6' at 05h 23m 17s chron time (error 02m 09s fast). If IE was 2.8' on the arc and HE was 10m, find the direction of the PL and the latitude where it cuts the DR longitude.

(3) At about 0330 ship's time on 1st May 1992, in DR longitude 150°E, the observed altitude of Polaris was 50° 46.8' bearing 005° (C) at 05h 30m 30s by chron (error nil). HE 14m var 1°E. Find the deviation of the compass, the direction of the PL and a position through which to draw it.

(4) On 6th March 1992, at 0200 ship's time in DR 20° 37'N 00° 00', the Pole star bore 356° (C). If variation was 3.7°W, find the deviation of the compass.

(5) On 13th Sept 1992, PM at ship in DR 37° 26'N 72° 46'E, the Pole star bore 350° (C) at 03h 59m 03s by chron (error 10m 03s slow). If variation was 10°E, find the deviation for the ship's head.

-o0o-

16

WORKED EXAMPLES

AND

EXERCISES - PLANETS

16.1 Latitude by meridian altitude - PLANET:-

On 15th June 1992, in DR 45° 00'S 91°10'E, the sextant meridian altitude of JUPITER was 35° 14.2'. If IE was 0.5' on the arc and HE was 9m, find the latitude and the PL.

			d h m s
Sext Alt	35° 14.2'	Approx LMT mer pass	15 17 02 00
IE (on)	(-) 00.5'	LIT (E)	(-) 06 04 40
Obs alt	35° 13.7'	Approx GMT mer pass	15 10 57 20
Dip (9m)	(-) 05.3'	declination	09° 48.0'N
App alt	35° 08.4'	d (-0.1)	00° 00.1'
Tot corrn	(-) 01.4'	declination	09° 47.9'N
T alt	35° 07.0' N → (Named same as azimuth)		
MZD	54° 53.0' S → (Named opposite to T alt)		
Dec	09° 47.9' N → (Contrary names subtract)		
Latitude	45° 05.1' S	PL :- E - W	

Notes

(1) The LMT of mer pass of the planet, taken directly from the almanac without any corrections is approximate only. It may be out by about three or four minutes. However, since the change of declination per hour (value of d) for planets is very small, no appreciable error creeps in by taking the LMT directly as tabulated in the almanac.

(2) Sometimes the chronometer time of the meridian altitude may be given. Then that time should be used after taking the usual precaution of obtaining the correct date and hours of GMT as explained in Chapter 12.

(3) In correcting the altitude of Venus and Mars, an additional correction (given in the almanac) has to be applied.

Sometimes, the question may also say 'State the correct GMT of meridian passage'. In such a case, proceed as follows:-

At mer pass, GHA + E (or - W) long = LHA = 360°

GHA + 91° 10' = 360° or GHA = 268°50.0'
From almanac, for GMT 1992 June 15d 10h, GHA = 254°13.4'
Approx. 58m ← Increment ← 014°36.6'
v correction (+2.2) for 58m → 000°02.1'
58m 18s ← Increment ← 014°34.5'

Precise GMT of mer pass = Jun 15d 10h 58m 18s **Answer**.

Notes:

(1) While extracting GHA of a planet from the almanac, v correction has to be applied. The value of v correction is applied to GHA just the same way d correction is applied to declination. V correction is always positive except for Venus where it could sometimes be plus and sometimes minus - this is indicated in the almanac.

(2) In referring to the almanac, it has been assumed that the date of GMT would be the same as that of ship i.e., 15th June. However, it may be possible that the date of GMT may be one day earlier or later than that assumed. It is therefore necessary to check up by applying LIT to the assumed GMT, as shown below, and alterations made, if necessary, to the GMT date and time.

GMT mer pass: Jun	15d	10h	58m	18s
LIT (E)	(+)	06	04	40
LMT mer pass: Jun	15	17	02	58

If the LMT so calculated fell on 14th or 16th June in this case, the entire computation of GMT would have to be repeated for the new date of GMT.

EXERCISE - 17

(Latitude by meridian altitude - PLANETS)

(1) On 5th May 1992, in DR 50° 10'S 64° 15'W, the observed meridian altitude of SATURN was 56° 00.3'. If HE was 10m, find the latitude and the direction of the PL. Also find, to the nearest second, the GMT of meridian passage.

(2) On 17th Jan 1992, in DR longitude 36° 40'E, the sextant meridian altitude of JUPITER was 37° 43.5' bearing N. If IE was 0.3' on the arc and HE was 12m, required the latitude and PL.

(3) On 14th Oct 1992, in DR longitude 110° 20'W, the sextant altitude of MARS on the meridian was 61° 14.5' South of the observer. If HE was 17m and IE was 3.6' off the arc, find the latitude and the PL.

(4) On 30th Nov 1992, in DR 56° 07'N 120° 04'E, the sextant meridian altitude of SATURN was 16° 24.0'. If IE was 0.6' on the arc and HE was 12m, find the latitude and the direction of the PL.

(5) On 3rd May 1992, in DR 35° 07'N 65° 30'W, the sextant meridian altitude of JUPITER was 66° 05.2' at 0h 07m 26s (error 06m 02s fast). If HE was 10m, and IE was 0.7' off the arc, required the latitude and the direction of the PL.

16.2 Azimuth - PLANET:-

On 1st Dec 1992, PM at ship in DR 36° 27'N 144° 44'E, VENUS bore 235° (C) at 09h 18m 08s chron time (error 10m 04s fast). If Var was 2.5°E, find the deviation for the ship's head.

	d	h	m	s		d	h	m	s
Chron		09	18	08	or		21	18	08
Error		(-)	10	04			(-)	10	04
GMT	01	09	08	04			21	08	04
LIT(E)		(+) 09	38	56			(+) 09	38	56
LMT	01	18	47	00			06	47	00

GMT 01d 09h 08m 04s

GHA		272° 02.3'	**From Nautical Tables**					
Incr		002° 01.0'	A	0.45 S				
v (-0.7)		(-) 00.1'	B	0.52 S				
GHA		274° 03.2'	C	0.97 S		Alternative		
Long(E)	(-)	144° 44.0'	T Az	232.1° (T)		T Az	232.1° (T)	
LHA		058° 47.2'	C Az	235.0° (C)		Var	2.5° E	
dec		24° 03.5'S	Error	2.9° W		M Az	229.6° M	
d (-0.4)		00° 00.1'	Var	2.5° E		C Az	235.0° (C)	
dec		24° 03.4'S	**Dev**	5.4° W		**Dev**	5.4° W	

Note: Working is very similar to that of azimuth - Sun except that v correction has to be applied to GHA just like the d correction for declination. V correction is always plus except in the case of Venus when it may sometimes be minus - this is indicated in the almanac.

Calculation of Azimuth by scientific calculator:

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

If LHA < 180°, P = LHA. If LHA > 180°, P = (360 - LHA). Naming of A, B and Azimuth is as stated under Az Sun (Chapter 14.2). **When P > 90°, the minus sign** obtained for the value **of A** is to be **ignored** as it is taken care of **by changing name of A** (see note 2 under Chapter 14.2).

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 36° 27.0'}}{\text{Tan 58° 47.2'}} = 0.4475539 \text{ S}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 24° 03.4'}}{\text{Sin 58° 47.2'}} = 0.5219732 \text{ S}$$

$$C = 0.9695271 \text{ S}$$

$$\text{Tan Az} = \frac{1}{\text{C (Cos 36° 27')}} = 1.2822749 \qquad \text{Az} = \text{S 52.1° W}$$

i.e., 232.1° (T)

EXERCISE 18

(Azimuth - PLANETS)

(1) On 23rd Sept 1992, at about 0019 at ship in DR 36° 08'S 78° 50'W, SATURN bore 286°(C). If ship's time difference was 5h from GMT and if variation was 3°W, find the deviation.

(2) On 1st May 1992, AM at ship in DR 40° 26'N 60° 40'E, Mars bore 096°(C) at 11h 51m 14s by chron (error 04m 06s slow). Variation was 3.7°W. Calculate the deviation of the compass.

(3) On 18th Jan 1992, in DR 00° 00' 62° 40'E, VENUS bore 120°(C) at 0310 ship's time (4h from GMT). If variation was 2°W, find the compass error and the deviation.

16.3 Longitude by chronometer - PLANET:-

On 31st Aug 1992 in DR 60° 06'N 66° 18'W, the sextant altitude of MARS was 41° 32.4' at 08h 15m 02s GMT. If HE was 10m and IE was 2.1' on the arc, calculate the direction of the PL and a position through which it passes.

Note: GMT is given so there is no ambiguity in the hours but the date of GMT is to be verified.

GMT	31	08	15	02
LIT(W)	(-)	04	25	12
LMT	31	03	49	50
GMT	**31**	**08**	**15**	**02**

Solution by Nautical Tables:

Hav LHA = Sec L . Sec D [Hav ZD - Hav (L ~ D)]

GHA	017° 22.6'	Sext alt	41° 32.4'
Incr	003° 45.5'	IE (on)	(-) 02.1'
v(+0.8)	(+) 00.2'	Obs alt	41° 30.3'
GHA	021° 08.3'	Dip (10m)	(-) 05.6'
dec	22° 56.9'N	App alt	41° 24.7'
d(+0.1)	00° 00.0'	Tot Corrn	(-) 01.1'
dec	22° 56.9'N	Addl corrn	(+) 00.1'
lat	60° 06.0'N	T alt	41° 23.7'
(L ~ D)	37° 09.1'	TZD	48° 36.3'

Nat Hav ZD	0.16938	Log Hav diff	8.83187
Nat Hav(L ~ D)	0.10148	Log Sec L	0.30235
Nat Hav diff	0.06790	Log Sec D	0.03581
		Log Hav LHA	9.17003

LHA	314° 45.7' ←(see note 1, Chapter 15.3)	A	1.73 S
GHA	021° 08.3'	B	0.60 N
Obs long	066° 22.6'W	C	1.13 S
DR lat	60° 06.0'N	Az 119.4° (T) ← Az	S 60.6° E

PL 029.4° - 209.4° through DR lat and Obs long. **Answer**.

Solution by scientific calculator:

$$\text{Cos P} = \frac{\text{Sin T alt} \quad \text{Sin lat . Sin dec}}{\text{Cos lat . Cos dec}}$$

Note:- If Lat and dec are same name (-), contrary names (+). Hence in the formula, (-) has been put above the (+). Entire numerator is Sin and entire denominator is Cos.

T alt = 41° 23.7' lat = 60° 06.0'N dec = 22° 56.9'N

$$\text{Cos P} = \frac{\text{Sin 41° 23.7'(-)Sin 60° 06.0' . Sin 22° 56.9'}}{\text{Cos 60° 06.0' . Cos 22° 56.9'}} = 0.7041772$$

P = 45° 14.2' (see note 1, Chapter 15.3)

LHA	=	314° 45.8'
GHA	=	021° 08.3'
Obs long	=	066° 22.5'W

To calculate azimuth by scientific calculator:

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

If LHA < 180°, P = LHA. If LHA > 180°, P = (360 - LHA). Naming of A, B and Azimuth is as stated before. When P > 90°, the minus sign obtained for the value of A is to be ignored as it is taken care of by changing name of A (see note 2, Chap. 14.2).

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan } 60° \ 06.0'}{\text{Tan } 45° \ 14.2'} = 1.7247456 \text{ S}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan } 22° \ 56.9'}{\text{Sin } 45° \ 14.2'} = 0.5963354 \text{ N}$$

$$C = 1.1284102 \text{ S}$$

$$\text{Tan Az} = \frac{1}{\text{C (Cos } 60° \ 06')} = 1.7777821$$

Az = S 60.6° E
i.e., 119.4° (T)

EXERCISE 19

(Longitude by chron - PLANETS)

(1) On 17th Jan 1992, AM at ship in DR 31° 41'N 100° 10'E the sextant altitude of VENUS was 19° 48.6' when the chron (error 02m 06s fast) showed 11h 41m 44s. If IE was 2.1' on the arc and HE was 12m, find the direction of the PL and a position through which to draw it.

(2) On 1st Dec 1992, PM at ship in DR 29° 56'S 106° 14'E, the sextant altitude of SATURN was 46° 21.8' when chron (error 05m 01s slow) showed 12h 18m 33s. If IE was 1.3' off the arc and HE was 14m, find the direction of the PL and the longitude where it crosses the DR lat.

(3) On 22nd Sept 1992, PM ship in DR 40° 21'S 140° 12'W, the sextant altitude of SATURN was 54° 58.6' when the chron (error 11m 31s fast) showed 04h 22m 31s. If HE was 20m and

IE was 3.2' on the arc, required the direction of the PL and a position through which it passes.

(4) On the morning of 30th Nov 1992, in DR 39° 50'N 100° 12'E, the observed altitude of MARS was 48° 41.2' at 11h 42m 52s chron time. The chron error was 01m 10s slow. If HE was 22m, find the direction of the PL and a position through which it passes.

(5) On 1st May 1992, PM at ship in DR 19° 54'S 179° 58'W, the sextant altitude of JUPITER was 52° 38.5' when the chron (error 01m 10s fast) showed 06h 21m 52s. If IE was 0.2' off the arc and HE was 17m, find the direction of the PL and a position through which it passes.

16.4 Intercept - PLANET:-

On 31st Aug 1992 in DR 60° 06'N 66° 18'W, the sextant altitude of MARS was 41°32.4', when GMT was 08h 15m 02s. If HE was 10m and IE was 2.1' on the arc, calculate the direction of the PL and a position through which it passes.

Note: Since GMT is given, there is no ambiguity the the hours. However, the correct date of GMT has to be ascertained.

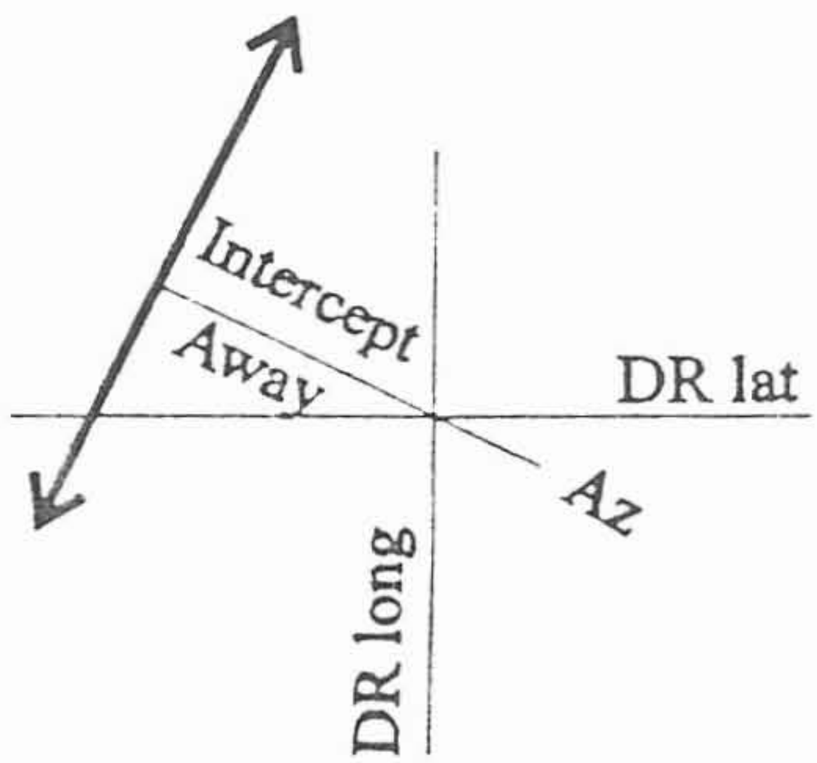
	d	h	m	s
GMT	31	08	15	02
LIT(W)	(-)	04	25	12
LMT	31	03	49	50

GMT 31d 08h 15m 02s

Solution by Nautical Tables:

Hav CZD = (Hav LHA . Cos L . Cos D) + Hav (L ~ D)

GHA	017° 22.6'	Sext alt	41° 32.4'
Incr	003° 45.5'	IE (on)	(-) 02.1'
v (+0.8)	(+) 00.2'	Obs alt	41° 30.3'
GHA	021° 08.3'	Dip (10m)	(-) 05.6'
Long W	066° 18.0'	App alt	41° 24.7'
LHA	314° 50.3'	Tot Corrn	(-) 01.1'
dec	22° 56.9'N	Addl corrn	00° 00.0'
d (+0.1)	(+) 00.0'	T alt	41° 23.6'
dec	22° 56.9'N	TZD	48° 36.4'
lat	60° 06.0'N	Log Hav LHA	9.16863
(L ~ D)	37° 09.1'	Log Cos L	9.69765
		Log Cos D	9.96421



Nat Hav sum	8.83049
Nat Hav Sum	0.06768
Nat Hav(L ~ D)	0.10149
Nat Hav CZD	0.16917
CZD	48° 34.4'
TZD	48° 36.4'
Int (AWAY)	02.0'
DR lat	60° 06.0'N
DR long	66° 18.0'W

A 1.73S	Az S 60.6° E
B 0.60N	i.e. 119.4°(T)
C 1.13S	PL 029.4 - 209.4°

Notes

(1) A rough sketch (not necessarily to scale) should be drawn to show that the student knows where the PL is to be drawn.

(2) Calculation of the latitude and longitude of the ITP (intercept terminal point) is not necessary in such a problem.

Solution by scientific calculator

Cos CZD = Cos P . Cos lat . Cos dec ± Sin lat . Sin dec

Note:- If Lat and dec are same name (+), contrary names (-). Hence in the formula, the (+) has been put above the (-). The signs are opposite to that for long by chron formula.

If LHA lies between 0° and 180°, P = LHA
If LHA is between 180° & 360°, P = 360 - LHA

P = 45° 09.7' lat = 60° 06.0'N dec = 22° 56.9'N

Cos CZD = Cos 45° 09.7'. Cos 60° 06.0' . Cos 22° 56.9'
(+) Sin 60° 06.0' . Sin 22° 56.9'
= 0.6616740

CZD = 48° 34.4'
TZD = 48° 36.4'
Int (AWAY) = 2.0'

Calculation of azimuth by scientific calculator:-

$A = \frac{\text{Tan lat}}{\text{Tan P}}$ $B = \frac{\text{Tan dec}}{\text{Sin P}}$ $\text{Tan Az} = \frac{1}{\text{C . Cos lat}}$

$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 60° 06.0'}}{\text{Tan 45° 09.7'}} = 1.7292670\ S$

$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 22° 56.9'}}{\text{Sin 45° 09.7'}} = 0.5971111\ N$

C = 1.1321559 S

$\text{Tan Az} = \frac{1}{\text{C (Cos 60° 06')}} = 1.7719003$ Az = S 60.6° E
i.e., 119.4° (T)

DR lat 60° 06.0'N DR long 66° 18.0'W
Intercept 2.0' AWAY
Azimuth 119.4°(T)
PL 029.4° - 209.4° **Answer.**

EXERCISE 20

(Intercept - PLANETS)

(1) On the morning of 30th Nov 1992, in DR 39° 50'N 100° 12'E, the observed altitude of MARS was 48° 41.2' at 11h 42m 52s chron time. The chron error was 01m 10s slow. If HE was 22m, find the direction of the PL and a position through which it passes.

(2) On 22nd Sept 1992, PM ship in DR 40° 21'S 140° 12'W, the sextant altitude of SATURN was 54° 58.6' when the chron (error 11m 31s fast) showed 04h 22m 31s. If HE was 20m and IE was 3.2' on the arc, required the direction of the PL and a position through which it passes.

(3) On 17th Jan 1992, AM at ship in DR 31° 41'N 100° 10'E the sextant altitude of VENUS was 19° 48.6' when the chron (error 02m 06s fast) showed 11h 41m 44s. If IE was 2.1' on the arc and HE was 12m, find the direction of the PL and a position through which to draw it.

(4) On 1st May 1992, PM at ship in DR 19° 54'S 179° 58'W, the sextant altitude of JUPITER was 52° 38.5' when the chron (error 01m 10s fast) showed 06h 21m 52s. If IE was 0.2' off the arc and HE was 17m, find the direction of the PL and a position through which it passes.

(5) On 1st Dec 1992, PM at ship in DR 29° 56'S 106° 14'E, the sextant altitude of SATURN was 46° 21.8' when chron (error 05m 01s slow) showed 12h 18m 33s. If IE was 1.3' off the arc and HE was 14m, find the direction of the PL and the longitude where it crosses the DR lat.

16.5 Ex-meridian - PLANET:-

On 30th Nov 1992, AM at ship in DR 34° 57'S 119° 50'E, the sextant altitude of MARS near the meridian was 13° 23.1' at 08h 00m 39s chron time (error 05m 01s slow). If HE was 17m and IE was 0.4' on the arc, find the direction of the PL and a position through which it passes. Note: Near the meridian means that working is to be by the ex-meridian method.

	d	h	m	s		d	h	m	s
Chron		08	00	39	or		20	00	39
Error		(+)	05	01			(+)	05	01
GMT		08	05	40		29	20	05	40
LIT(E)	(+)	07	59	20		(+)	07	59	20
LMT*		16	05	00		30	04	05	00

GMT 29d 20h 05m 40s

Solution by Nautical Tables:

GHA	248° 43.5'	Sext alt	31° 23.1'
Incr	001° 25.0'	IE (on)	(-) 00.4'
v(+2.5)	000° 01.1'	Obs alt	31° 22.7'
GHA	250° 08.7'	Dip (17m)	(-) 07.3'
long (E)	119° 50.0'	App alt	31° 15.4'
LHA	009° 58.7'	Tot Corm	(-) 01.6'
dec	23° 05.0'N	Addl corm	(+) 00.2'
d (0.0)	00° 00.0'	T alt	31° 14.0' N
dec	23° 05.0'N	TZD	58° 46.0' S
		Reduction #	(-) 46.2'
A 03.97N		MZD	57° 59.8' S
B 02.46N		dec	23° 05.0' N
C 06.43N		Obs lat	34° 54.8' S
Az N10.7°W		DR long	119° 50.0' E
i.e., 349.3° (T)		PL	079.3°- 259.3°

* Approx LMT mer pass given in that day's page of the almanac is 03h 24m. So LMT of sight must be 04h not 16h.

Working steps to obtain Reduction from Nautical Tables:-

From Table I - value F (Burton's) or value A (Norie's)	=	1.75
From Table II, First Correction	=	46.4'
From Table III, Second Correction	=	(-) 00.2'
Reduction to the TZD observed	=	46.2'

Notes

(1) Working is similar to Ex-meridian Sun (Chapter 14.6) except that v correction has to be applied to GHA and an additional correction is sometimes necessary for Mars & Venus.

(2) Ex-meridian star can also be worked by the Haversine formula as mentioned in Chapter 14.6 (note: 10).

Solution by scientific calculator:-

Cos MZD = Cos TZD + [(1 - Cos P) . Cos DR lat . Cos dec]

Note: TZD 58° 46.0', P 9° 58.7', lat 34° 57'S, dec 23° 05.0'N

= Cos 58°46.0' + [(1- Cos 9°58.7').Cos 34°57'.Cos 23°05.0']

= 0.5299304. Hence MZD, by scientific calculator, = 58° 00.0'

MZD	= 58° 00.0' S	A = Tan lat / Tan P	=	03.9675669 N
dec	= 23° 05.0' N			
Obs lat	= 34° 55.0' S	B = Tan dec / Sin P	=	02.4596192 N
DR long	= 119° 50.0' E			----------
		C	=	06.4271862 N

$$\text{Tan Az} = \frac{1}{C \,.\, \text{Cos lat}} = 0.1897461 \quad \text{Az} = \text{N}10.7°\text{W} = 349.3° \text{ (T)}$$

PL = 079.3° - 259.3°

Exercise 21

(Ex-meridian altitude - PLANETS)

(1) On 3rd May 1992, PM at ship in DR 40° 11'N 65° 30'W, the sextant altitude of JUPITER near the meridian was 60° 45.4' at 00h 13m 50s chron time (error 04m 10s slow). If IE was 0.3' on the arc and HE was 14m, find the direction of the PL and a position through which it passes.

(2) On 30th Nov 1992, PM at ship in DR 56° 04'N 120° 04'E, the sextant altitude of SATURN near the meridian was 16° 05.6' at 09h 01m 49s chron time (error 02m 05s fast). If IE was nil and HE was 17m, find the direction of the PL and the latitude where it cuts the DR longitude.

(3) On 14th Oct 1992, during morning twilight in DR 63° 55'N 110° 20'W, the observed altitude of MARS near the meridian was 49° 09.5' at 01h 15m 20s by chron (error 01m 00s slow). HE 10m. Find the direction of the PL and a position through which to draw it.

(4) On 17th Jan 1992, AM at ship in DR 45° 02'S 36° 42'E, the sextant altitude of JUPITER near the meridian was 37° 06.8' when chron (error 01m 06s slow) showed 01h 26m 14s. If IE was 0.6' off the arc and HE was 12m, find the direction of the PL and a position through which it passes.

(5) On 4th May 1992, AM at ship in DR 52° 13'S 64° 15'W, the observed altitude of SATURN near the meridian was 53° 07.8' at 10h 59m 51s chron time. If chron error was 01m 51s fast and HE was 20m, find the direction of the PL and the lat where it cuts the DR long.

17

WORKED EXAMPLES

AND EXERCISES - MOON

17.1 Amplitude - MOON:

On 2nd Sept 1992, in DR 40° 02'S 173° 18'E, the Moon set bearing 243° (C). If variation was 2°W, find the deviation of the compass for the ship's head.

Notes

(1) The LMT of Moonrise/Moonset given in the almanac is approximate only and requires correction for the longitude of the observer.

(2) First write down the approximate LMT of Moonrise/Moonset for the date in question. Compare it with the approximate LMT of the EARLIER occurrence of the same phenomenon if longitude is EAST, and the NEXT occurrence if the longitude is WEST, to get the daily difference.

(3) Obtain 'longitude correction' by the formula, given below, in which longitude is in degrees and decimal of a degree and daily difference is in minutes of time.

$$\text{Longitude correction} = \frac{\text{longitude x daily difference}}{360}$$

(4) Obtain the long. corrn. and apply it to the approx LMT of Moon/Moonset for the date in question (if long. is E subtract and if W, add). The result obtained is the LMT of the occurrence on the day in question. By applying LIT to it, we get the GMT. The long. corrn and the LMT may each be rounded off to the nearest whole minute.

(5) The rest of the working is similar to that of amplitude Sun, explained in Chapter 14.3.

Approx LMT Moonset Sept	02d 24h 19m*
Long E, Earlier Moonset	01d 23h 14m
Daily difference	01h 05m = 65m

* Owing to the fact that the interval between successive occurrences of the same phenomenon of the Moon (mer pass to mer pass, Moonrise to Moonrise and Moonset to Moonset) is more than 24hours, it may sometimes happen that, on a given day, one of the phenomena does not occur In the worked example here, there is no Moonset on 2nd Sept. The nearest one tabulated in the almanac i.e., Sept 02d 24h 19m really means 3d 00h 19m.

$$\text{Long corrn} = \frac{\text{long x dd}}{360} = \frac{173.3 \times 65}{360} = 31\text{m}$$

Approx LMT Moonset	02d 24h 19m
Long East Corrn	(-) 31m
Correct LMT Moonset	02d 23h 48m
LIT (E)	(-) 11h 33m
Correct GMT Moonset	02d 12h 15m

If, for any reason, the exact GMT is required, put LHA = 360° and work back the GMT, to the nearest second, from the almanac as explained under mer alt star - Chapter 15.1 and mer alt planet - Chapter 16.1.

dec	21° 18.5'S
d(+6.1)	01.5'
dec	21° 20.0'S
lat	40° 02.0'S

From Tables or by the formula:
Sin Amp = Sin dec . Sec lat

T amp	=	W 28.4°S
T Az	=	241.6° (T)
Var	=	2.0° W
M Az	=	243.6° (M)
C Az	=	243.0° (C)
Dev	=	0.6° E

EXERCISE 22

(Amplitude - MOON)

(1) On 2nd May 1992, in DR 20° 12'S 164° 40'E, the Moon set bearing 290°(C). If variation was 2°W, find the deviation of the compass for the ship's head.

(2) On 31st Aug 1992, in DR 00°01'N 174°56'W, the Moon rose bearing 102°(C). If variation was 1.7°E, find the deviation.

(3) On 4th March 1992, in DR 42° 20'N 64° 18'E, the rising Moon bore 089°(C). If variation was 10°E, find the deviation of the compass.

(4) On 2nd Sept 1992, the Moon set bearing 260°(C) in DR 35° 06'S 74° 12'E. If variation was 12°WE, find the deviation.
Note: Approx LMT Moonset 02d 24h 04m (3d 00h 04m) and 01d 23h 06m. So at Greenwich, there is no Moonset on 2nd. However, the application of W long. corrn. to Moonset of 3rd will give the required LMT as 2nd.

(5) On 21st Jan 1992, the Moon rose bearing 080°(C) in DR 30° 10'S 40° 20'E. If variation was 5.3°W, find the deviation.

17.2 Lat by mer alt - MOON:-

On 25th Feb 1992, in DR 10° 05'N 103°16'E, the sextant meridian altitude of the Moon's UL was 56° 14.9'. If IE was 1.6' on the arc & HE was 12m, find the latitude and the PL.

			d	h	m
Sext Alt	56° 14.9'	Approx LMT mer pass	25	05	52
IE (on)	(-) 01.6'	Long E, Earlier	24	05	00
Obs alt	56° 13.3'	Daily difference	.		52
Dip (12m)	(-) 06.1'	Long corm = 103.3(52)/360 =			- 15
App alt	56° 07.2'	Approx LMT mer pass	25	05	52
Main corm	(+) 42.1'	Correct LMT mer pass	25	05	37
HP (55.8)	(+) 03.1'	LIT (E)	(-)	06	53
	56° 52.4'	Correct GMT mer pass	24	22	44
UL corm	(-) 30.0'	declination	23° 21.6'S		
T alt	56° 22.4'S	d (+4.3)	(-) 03.2'		
MZD	33° 37.6'N	declination	23° 24.8'S		
Dec	23° 24.8'S				
Latitude	10° 12.8'N	PL :- E - W			

Notes

(1) Method of obtaining GMT of mer pass is similar to that of amplitude Moon - Chapter 17.1

(2) Correction of altitude of Moon is explained in Chapter 10.2.

EXERCISE - 23

(Latitude by meridian altitude - MOON)

(1) On 1st Dec 1992, in DR 40° 12'S 164° 48'E, the observed meridian altitude of the Moon's LL was 56° 40.3'. If HE was 14m, find the latitude and the direction of the PL.

(2) On 21st July 1992, in DR 37° 22'N 96° 36'W, the sextant meridian altitude of the Moon's UL was 62° 01.1'. If IE was 0.4' off the arc & HE was 17m, required the latitude and PL.

(3) On 26th Feb 1992, in DR 50° 10'S 64° 12'E, the observed altitude of the Moon's LL on the meridian was 63° 58.0'. If HE was 20m, find the latitude and the PL.

(4) On 2nd Sept 1992, in DR longitude 175° 16'E, the sextant meridian altitude of the Moon's UL was 23° 27.8' South of the observer. If IE was 0.2' off the arc and HE was 14m, find the latitude and the direction of the PL.

(5) On 29th Nov 1992, in DR longitude 140° 12'W, the sextant meridian altitude of the Moon's UL was 62° 15.6' North of the observer. If HE was 10m, and IE was 0.6' on the arc, required the latitude and the direction of the PL.

17.3 Azimuth - MOON:-

On March 6th 1992, AM at ship in DR 30° 30'N 140° 11'W the Moon bore 105° (C) at 07h 35m 02s chron time (error 04m 06s fast). If variation was 2°E, find the deviation.

	d	h	m	s		d	h	m	s
Chron		07	35	02	or		19	35	02
Error		(-)	04	06			(-)	04	06
GMT		07	30	56		06	19	30	56
LIT(W)	(-)	09	20	44		(-)	09	20	44
LMT		22	10	12		06	10	10	12

GMT 06d 19h 30m 56s

GHA	080° 46.2'	dec	09° 19.7'N
Incr	007° 22.9'	d (12.1)	(+) 06.2'
v (14.1)	(+) 07.2'	dec	09° 25.9'N
GHA	088° 16.3'	lat	30° 30.0'N
Long(W)	(-) 140° 11.0'	A	0.462S
LHA	308° 05.3'	B	0.211N
Azimuth = S 87.8° E or 102.2° (T) ←		C	0.251S

Alternative 1			Alternative 2		
T Az	102.2°	(T)	T Az	102.2°	(T)
C Az	105.0°	(C)	Var	2.0°	E
Error	2.8°	W	M Az	100.2°	(M)
Var	2.0°	E	C Az	105.0°	(C)
Dev	4.8°	W	Dev	4.8°	W

Calculation of Azimuth by scientific calculator:

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

If LHA < 180°, P = LHA. If LHA > 180°, P = (360 - LHA). Naming of A, B and Azimuth is as stated before. When P > 90°, the minus sign obtained for the value of A is to be ignored as it is taken care of by changing name of A (see Chapter 14.2).

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 30° 30.0'}}{\text{Tan 51° 54.7'}} = 0.4616766 \text{ S}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 09° 25.9'}}{\text{Sin 51° 54.7'}} = 0.2110597 \text{ N}$$

$$C = 0.2506169 \text{ S}$$

$$\text{Tan Az} = \frac{1}{\text{C (Cos 30° 30')}} = 4.6309411$$

Az = S 77.8° E
i.e., 102.2° (T)

EXERCISE 24

(Azimuth - MOON)

(1) On 19th Jan 1992, PM at ship in DR 40° 58'N 175° 20'W the Moon bore 100° (C) at 07h 40m 59s chron time (error 01m 01s slow). If variation was 6°W, find the deviation.

(2) On 31st Aug 1992, PM at ship in DR 36° 03'N 146° 50'E the Moon bore 230° (C) at 08h 14m 56s chron time (error 02m 06s fast). If variation was 3°W, find the deviation.

(3) On 30th Nov 1992, at 1950 hours at ship in DR 20° 29'S 017° 46'E the Moon bore 280° (C). If ship's time difference was (GMT + 1h) and variation was 3.5°E, find the deviation.

17.4 Longitude by chronometer - MOON:-

On 25th Feb 1992, AM at ship in DR 20° 04'S 90° 04'W, the sextant altitude of the Moon's UL was 52° 26.8' at 02h 56m 17s chron time (error 04m 01s fast). If HE was 19m and IE was 0.6' off the arc, calculate the direction of the PL and a position through which it passes.

	d	h	m	s		d	h	m	s
Chron		02	56	17	or		14	56	17
Error		(-)	04	01			(-)	04	01
GMT		02	52	16		25	14	52	16
LIT(W)	(-)	06	00	16		(-)	06	00	16
LMT		20	52	00		25	08	52	00

GMT 25d 14h 52m 16s

Solution by Nautical Tables:

Hav LHA = Sec L . Sec D [Hav ZD - Hav (L ~ D)]

GHA	117° 43.5'	Sext alt	52° 26.8'
Incr	012° 28.3'	IE (off)	(+) 00.6'
v(+9.7)	(+) 08.5'	Obs alt	52° 27.4'
GHA	130° 20.3'	Dip (19m)	(-) 07.7'
		App alt	52° 19.7'
		Main corrn	(+) 45.2'
dec	24° 16.3'S	HP (55.4)	(+) 02.9'
d(+2.3)	00° 02.0'		53° 07.8'
dec	24° 18.3'S	UL corrn	(-) 30.0'
lat	20° 04.0'S	T alt	52° 37.8'
(L ~ D)	04° 14.3'	TZD	37° 22.2'

Nat Hav ZD	0.10264	Log Hav diff	9.00548
Nat Hav(L ~ D)	0.00137	Log Sec L	0.02720
Nat Hav diff	0.10127	Log Sec D	0.04032
		Log Hav LHA	9.07300

LHA	040° 14.1' ←(see note 1, Chapter 15.3)	A	0.43 N
GHA	130° 20.3'	B	0.70 S
Obs long	090° 06.2'W	C	0.27 S
DR lat	20° 04.0'S	Az 255.9° (T) ← Az S 75.9° W	

PL 165.9° - 345.9° through DR lat and Obs long. Answer.

Solution by scientific calculator:

$$\text{Cos P} = \frac{\text{Sin T alt} \quad \text{Sin lat . Sin dec}}{\text{Cos lat . Cos dec}}$$

Note:- If Lat and dec are same name (-), contrary names (+). Hence in the formula, (-) has been put above the (+). Entire numerator is Sin and entire denominator is Cos.

T alt = 52° 37.8' lat = 20° 04.0'S dec = 24° 18.3'S

$$\text{Cos P} = \frac{\text{Sin } 52° \ 37.8' (-) \text{Sin } 20° \ 04' . \text{ Sin } 24° \ 18.3'}{\text{Cos } 20° \ 04' \ . \text{ Cos } 24° \ 18.3'} = 0.7634079$$

P = 40° 14.1' (see note 1, Chapter 15.3)

LHA	=	040° 14.1'
GHA	=	130° 20.3'
Obs long		090°06.2'W

To calculate azimuth by scientific calculator:

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

If LHA < 180°, P = LHA. If LHA > 180°, P = (360 - LHA). Naming of A, B and Azimuth is as stated before. When P > 90°, the minus sign obtained for the value of A is to be ignored as it is taken care of by changing name of A (see note 2, Chap. 14.2).

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan } 20° \ 04.0'}{\text{Tan } 40° \ 14.1'} = 0.4317253 \text{ N}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan } 24° \ 18.3'}{\text{Sin } 40° \ 14.1'} = 0.6991879 \text{ S}$$

C = 0.2674626 S

$$\text{Tan Az} = \frac{1}{\text{C (Cos } 20° \ 04')} = 3.9804792$$

Az = S 75.9° W
i.e., 255.9° (T)

EXERCISE 25

(Longitude by chronometer - MOON)

(1) On 1st Sept 1992, PM at ship in DR 20° 58'N 120° 19'W the sextant altitude of the Moon's LL was 33° 06.6' at 02h 35m 55s chron time (error 10m 42s slow). If IE was 0.3' off the arc and HE was 30m, find the direction of the PL and a position through which to draw it.

(2) On 22nd Sept 1992, AM at ship in DR 10° 02'S 76° 50'E, the sextant altitude of the Moon's LL was 44° 31.7' at 00h 17m 21s chron time (error 07m 28s slow). If IE was 0.6' on the arc and HE was 14m, find the direction of the PL and the longitude where it cuts the DR lat.

(3) On 6th March 1992, AM at ship in DR 00° 00' 60° 50'W, the sextant altitude of the Moon's UL was 44° 28.9' at 02h 44m 48s chron time (error 11m 16s fast). If HE was 15m and IE was 0.4' off the arc, find the direction of the PL and a position through which it passes.

(4) On 25th Feb 1992, AM at ship in DR 35° 03'S 87° 11'E, the observed altitude of the Moon's UL was 46° 29.5' at 03h 16m 26s chron time (error 05m 06s fast). If HE was 18m, find the direction of the PL and a position through which it passes.

(5) On 30th Nov 1992, PM at ship in DR 27° 45'S 140° 20'W, the observed altitude of the Moon's UL was 40° 18.8' at 11h 10m 08s chron time (error 00m 02s slow). If HE was 10m, find the direction of the PL and the longitude where it cuts the DR lat.

17.5 Intercept - MOON:-

On 25th Feb 1992, AM at ship in DR 20° 04'S 90° 04'W, the sextant altitude of the Moon's UL was 52° 26.8' at 02h 56m 17s chron time (error 04m 01s fast). If HE was 19m and IE was 0.6' off the arc, calculate the direction of the PL and a position through which it passes.

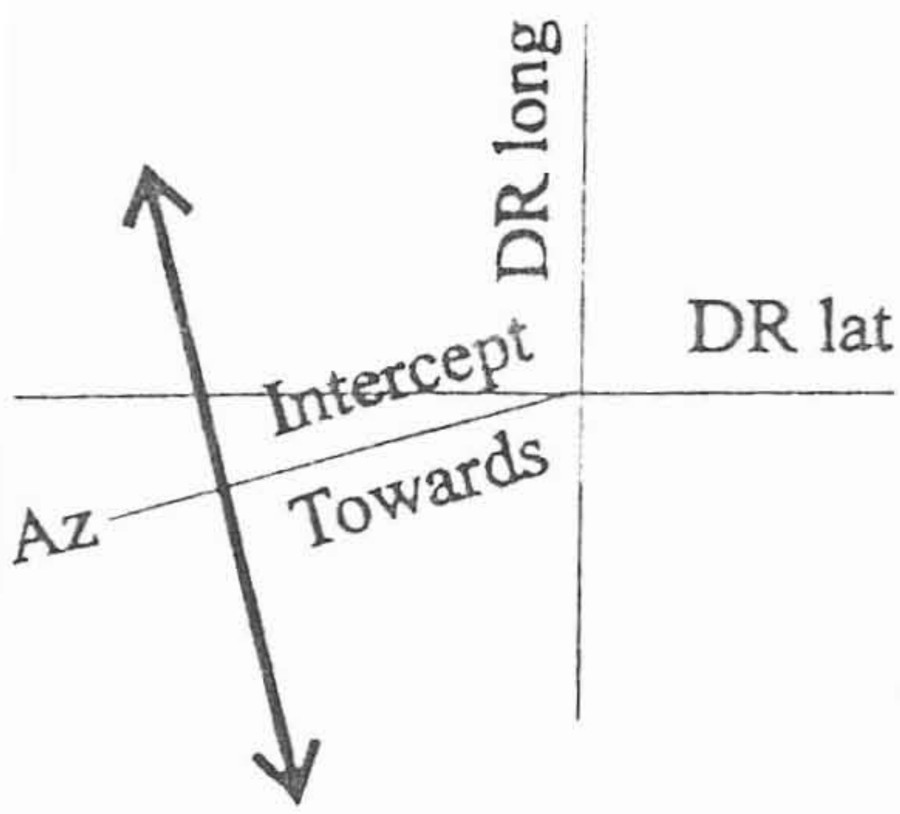
	d	h	m	s		d	h	m	s
Chron		02	56	17	or		14	56	17
Error		(-)	04	01			(-)	04	01
GMT		02	52	16		25	14	52	16
LIT(W)	(-)	06	00	16		(-)	06	00	16
LMT		20	52	00		25	08	52	00

GMT 25d 14h 52m 16s

Solution by Nautical Tables:

Hav CZD = (Hav LHA . Cos L . Cos D) + Hav (L ~ D)

GHA	117° 43.5'	Sext alt	52° 26.8'
Incr	012° 28.3'	IE (off)	(+) 00.6'
v (+9.7)	(+) 08.5'	Obs alt	52° 27.4'
GHA	130° 20.3'	Dip (19m)	(-) 07.7'
Long W	090° 04.0'	App alt	52° 19.7'
LHA	040° 16.3'	Main corrn	(+) 45.2'
dec	24° 16.3'S	HP (55.4)	(+) 02.9'
d (+2.3)	(+) 02.0'		53° 07.8'
dec	24° 18.3'S	UL corrn	(-) 30.0'
lat	20° 04.0'S	T alt	52° 37.8'
(L ~ D)	04° 14.3'	TZD	37° 22.2'



Log Hav LHA	9.07374
Log Cos L	9.97280
Log Cos D	9.95969
Log Hav sum	9.00623
Nat Hav Sum	0.10145
Nat Hav(L ~ D)	0.00137
Nat Hav CZD	0.10282
CZD	37° 24.3'
TZD	37° 22.2'
Int (Towards)	2.1'
Az = S75.9°W = 255.9°	
DR lat	20° 04.0'S
DR long	90° 04.0'W
PL = 165.9 - 345.9° (T)	

A	0.431N
B	0.699 S
C	0.268 S

Notes

(1) A rough sketch (not necessarily to scale) should be drawn to show that the student knows where the PL is to be drawn.

(2) Calculation of the latitude and longitude of the ITP (intercept terminal point) is not necessary in such a problem.

Solution by scientific calculator

Cos CZD = Cos P . Cos lat . Cos dec ± Sin lat . Sin dec

Note:- If Lat and dec are same name (+), contrary names (-). Hence in the formula, the (+) has been put above the (-). The signs are opposite to that for long by chron formula.

If LHA lies between 0° and 180°, P = LHA
If LHA is between 180° & 360°, P = 360 - LHA

P = 40° 16.3' lat = 20° 04.0'S dec = 24° 18.3'S

Cos CZD = Cos 40° 16.3'. Cos 20° 04.0' . Cos 24° 18.3'
(+) Sin 20° 04.0' . Sin 24° 18.3'
= 0.7943730 CZD = 37° 24.2'
TZD = 37° 22.2'
Int (Tow) = 2.0'

Calculation of azimuth by scientific calculator:-

$A = \frac{\text{Tan lat}}{\text{Tan P}}$ $B = \frac{\text{Tan dec}}{\text{Sin P}}$ $\text{Tan Az} = \frac{1}{\text{C . Cos lat}}$

$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 20° 04.0'}}{\text{Tan 40° 16.3'}} = 0.4311654\ \text{N}$

$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 24° 18.3'}}{\text{Sin 40° 16.3'}} = 0.6986596\ \text{S}$

C = 0.2674942 S

$\text{Tan Az} = \frac{1}{\text{C (Cos 20° 04')}} = 3.9800090$ Az = S 75.9° W
i.e., 255.9° (T)

EXERCISE 26

(Intercept - MOON)

(1) On 6th March 1992, AM at ship in DR 00° 00' 60° 50'W, the sextant altitude of the Moon's UL was 44° 28.9' at 02h 44m 48s chron time (error 11m 16s fast). If HE was 15m and IE was 0.4' off the arc, find the direction of the PL and a position through which it passes.

(2) On 30th Nov 1992, PM at ship in DR 27° 45'S 140° 20'W, the observed altitude of the Moon's UL was 40° 18.8' at 11h 10m 08s chron time (error 00m 02s slow). If HE was 10m, find the intercept and the direction of the PL.

(3) On 1st Sept 1992, PM at ship in DR 20° 58'N 120° 19'W the sextant altitude of the Moon's LL was 33° 06.6' at 02h 35m 55s chron time (error 10m 42s slow). If IE was 0.3' off the arc and HE was 30m, find the intercept and the PL.

(4) On 22nd Sept 1992, AM at ship in DR 10° 02'S 76° 50'E, the sextant altitude of the Moon's LL was 44° 31.7' at 00h 17m 21s chron time (error 07m 28s slow). If IE was 0.6' on the arc and HE was 14m, find the intercept and PL.

(5) On 25th Feb 1992, AM at ship in DR 35° 03'S 87° 11'E, the observed altitude of the Moon's UL was 46° 29.5' at 03h 16m 26s chron time (error 05m 06s fast). If HE was 18m, find the direction of the PL and the intercept.

17.6 - Ex-meridian altitude - MOON:-

On 29th Nov 1992, in DR 36° 08'S 96° 40'E, the sextant altitude of the Moon's UL near the meridian was 68° 53.7' at 09h 18m 24s chron time (error 05m 01s slow). If IE was 0.2' off the arc and HE was 14m, find the direction of the PL and a position through which it passes.

	d	h	m	s		d	h	m	s
Chron		09	18	24	or		21	18	24
Error		(+)	05	01			(+)	05	01
GMT	29	09	23	25			21	23	25
LIT(E)	(+)	06	26	40		(+)	06	26	40
LMT	29	15	50	05			03	50	05

GMT 29d 09h 23m 25s

Solution by Nautical Tables:

GHA	256° 09.9'	Sext alt	68° 53.7'
Incr	005° 35.2'	IE (off)	(+) 00.2'
v(13.7)	000° 05.4'	Obs alt	68° 53.9'
GHA	261° 50.5'	Dip (14m)	(-) 06.6'
Long E	096° 40.0'	App alt	68° 47.3'
LHA	358° 30.5'	Main Corrn	00° 31.2'
dec	15° 12.8'S	HP (54.7)	00° 03.3'
d (-9.2)	(-) 03.6'		69° 21.8'
dec	15° 09.2'S	UL corrn	(-) 30.0'
		T alt	68° 51.8'N
A 28.155N		TZD	21° 08.2'S
B 10.403S		Reduction	(-) 02.6'*
C 17.752N		MZD	21° 05.6'S
		dec	15° 09.2'S
Az N4.0°E = 004.0°(T)		Obs lat	36° 14.8'S
PL 094.0°- 274.0°(T)		DR long	96° 40.0'E

* Working steps to obtain Reduction from Nautical Tables:-

From Table I - value F (Burton's) or value A (Norie's) = 4.3
From Table II, First Correction = 2.6'
From Table III, Second Correction = (-) 0.0'
Reduction to the TZD observed = 2.6'

Notes:

(1) In this problem, no hint of ship's time is given but approx LMT of mer pass Moon from the almanac is 1608. So correct LMT must be very near that time.
(2) The working is similar to that of Ex-meridian altitude Sun.
(3) MZD can also be obtained by the Haversine formula:-
Hav MZD = Hav TZD - (Hav LHA . Cos L . Cos D).

Solution by scientific calculator:-

Cos MZD = Cos TZD + [(1 - Cos P) . Cos DR lat . Cos dec]

TZD 21° 08.2' P 1° 29.5' DR lat 36° 08'S dec 15° 09.2'S

= Cos 21°08.2'+[(1- Cos 1°29.5') . Cos 36°08' . Cos 15°09.2'

= 9329871. Hence MZD by scientific calculator = 21° 05.7'

MZD = 21° 05.7' S
dec = 15° 09.2' S
Obs lat = 36° 14.9' S
DR long = 96° 40.0' E

$A = \frac{\text{Tan lat}}{\text{Tan P}}$ = 28.155720 N

$B = \frac{\text{Tan dec}}{\text{Sin P}}$ = 10.403512 S

C = 17.752209 N

$\text{Tan Az} = \frac{1}{\text{C . Cos lat}}$ = 0.0698495 Az = N04.0°E = 004.0° (T)

PL = 094.0° - 274.0° (T)

Exercise 27

(Ex-meridian altitude - MOON)

(1) On 2nd Sept 1992, in DR 39° 57'N 179° 56'E, the sextant altitude of the Moon's UL near the meridian was 29° 14.2' when chron (error 02m 23s fast) showed 04h 03m 49s. If IE was 0.3' off the arc and HE was 18m, find the direction of the PL and a position through which it passes.

(2) On 26th Feb 1992, in DR 45° 04'S 000° 20'W, the sextant altitude of the Moon's LL near the meridian was 68° 58.1' when chron (error 02m 30s slow) showed 06h 59m 00s. If IE was 0.1' on the arc and HE was 14m, find the direction of the PL and the lat where it cuts the DR long.

(3) On 6th March 1992, in EP 45° 40'N 60° 12'W, the sextant altitude of the Moon's UL near the meridian was 52° 19.4' when chron (error 14m 12s slow) showed 04h 47m 16s. If IE was 0.4' off the arc and HE was 15m, find the direction of the PL and a position through which to draw it.

(4) On 1st Dec 1992, in DR 46° 12'S 90° 20'E, the sextant altitude of the Moon's UL near the meridian was 49° 46.8' when chron (error 05m 09s fast) showed 11h 03m 58s. If IE was 0.6' on the arc and HE was 10m, find the direction of the PL and a position through which it passes.

(5) On 23rd Sept 1992, in EP 58° 02'N 178° 50'W, the sextant altitude of the Moon's UL near the meridian was 40° 38.5' at 09h 52m 10s chron time. If chron error was 11m 04s fast, IE was 0.7' on the arc and HE was 17m, find the direction of the PL and the lat where it cuts the DR long.

18

GRAPHICAL COMBINATION OF SIGHTS

Graphical combination of sights means the construction of a small part of a Mercator Chart to scale, plotting therein the results of two or more astronomical sights and thence obtaining the position of the vessel.

The Mercator Chart has been described in Chapter 7. However, a few important points are emphasised here.

On a Mercator Chart:-

(1) All meridians are parallel.
(2) A nautical mile is equal to one minute of d'lat.
(3) All distances, whether North-South, East-West or oblique, are in expressed in nautical miles.
(4) All North-South distances, in nautical miles, are equal to minutes of d'lat.
(5) The East-West distance between the meridians of two places, measured along the latitude scale, is called departure and is expressed in nautical miles.

(6) The East-West distance between the meridians of two places, measured along the longitude scale = d`long between them.

The conversion of dep into d`long, and vice versa, by formula and by Traverse Tables, has been explained earlier in this book.

Plotting can be done on plain paper - graph paper is not essential. The scale should be clearly mentioned. The most convenient scales to use are 1 cm : 1M or 1 inch : 1 M. Where practicable, scales involving fractions should be avoided so as to minimise the chances of error especially when in a hurry.

When transferring a PL from one position to another, it is suggested that, in order to maintain accuracy, runs in excess of about 10M should be calculated. If large distances are plotted to scale, the scale would have to be small with resultant loss of accuracy.

It is also possible to combine two sights by trigonometry but that procedure would be tedious and the chances of clerical error are great. It is therefore not recommended.

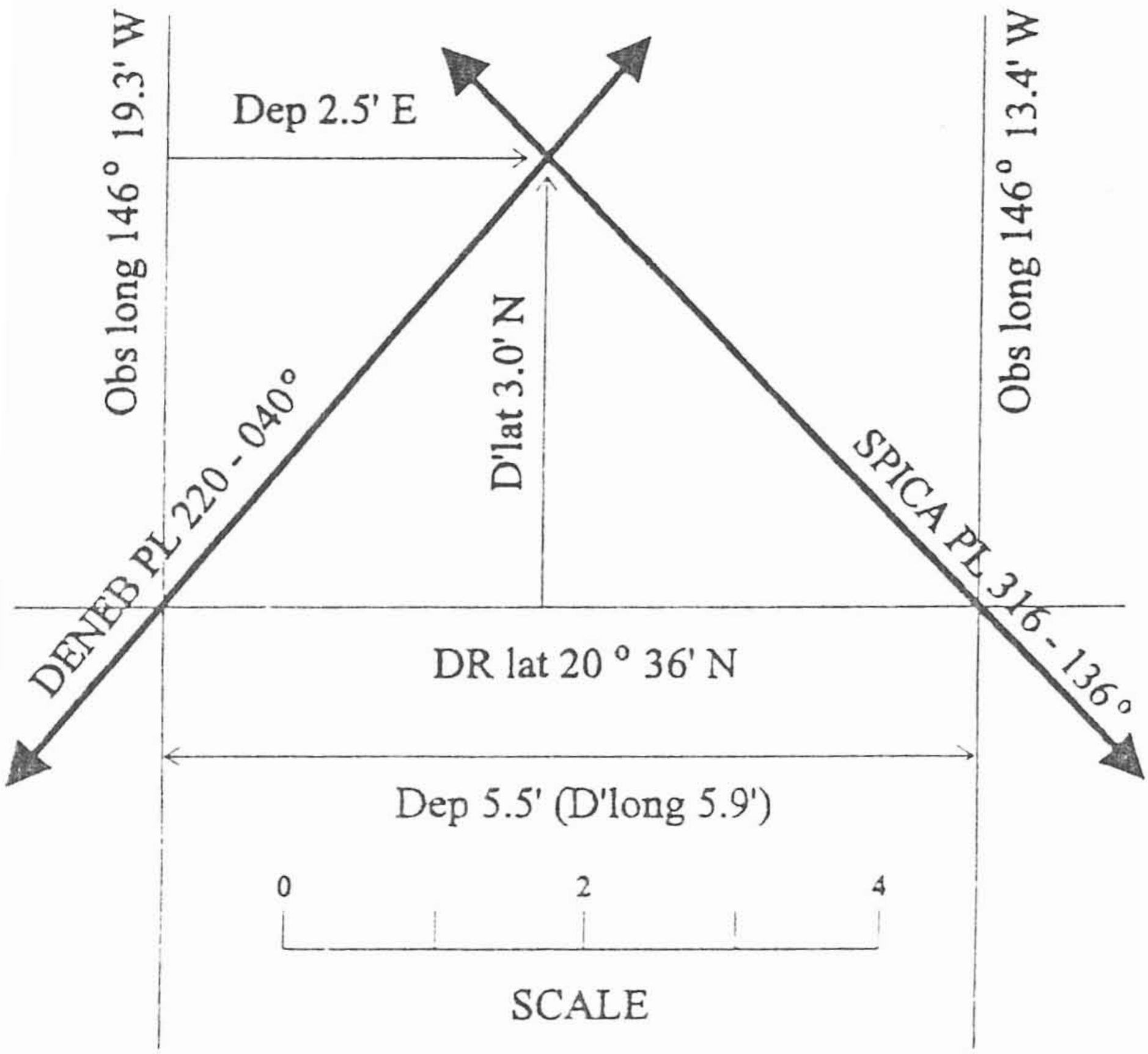
When one of two PL`s runs exactly E - W, it is possible to calculate the longitude of the fix without plotting as shown in worked examples A4, B1 and B2 of this chapter.

A - SIMULTANEOUS OBSERVATIONS

A 1 - Two longitudes by chronometer:-

In DR 20° 36`N 146° 11'W, star SPICA bore 046° (T) giving an Obs long of 146° 13.4'W. At the same time, star DENEB bore 130° (T) giving an Obs long of 146° 19.3'W. Find the position of the ship.

D`long between the Obs long`s = 5.9`. For m`lat 20.6°, dep = 5.5` (quick interpolation method by T.T. is explained in Chapter 6.3).

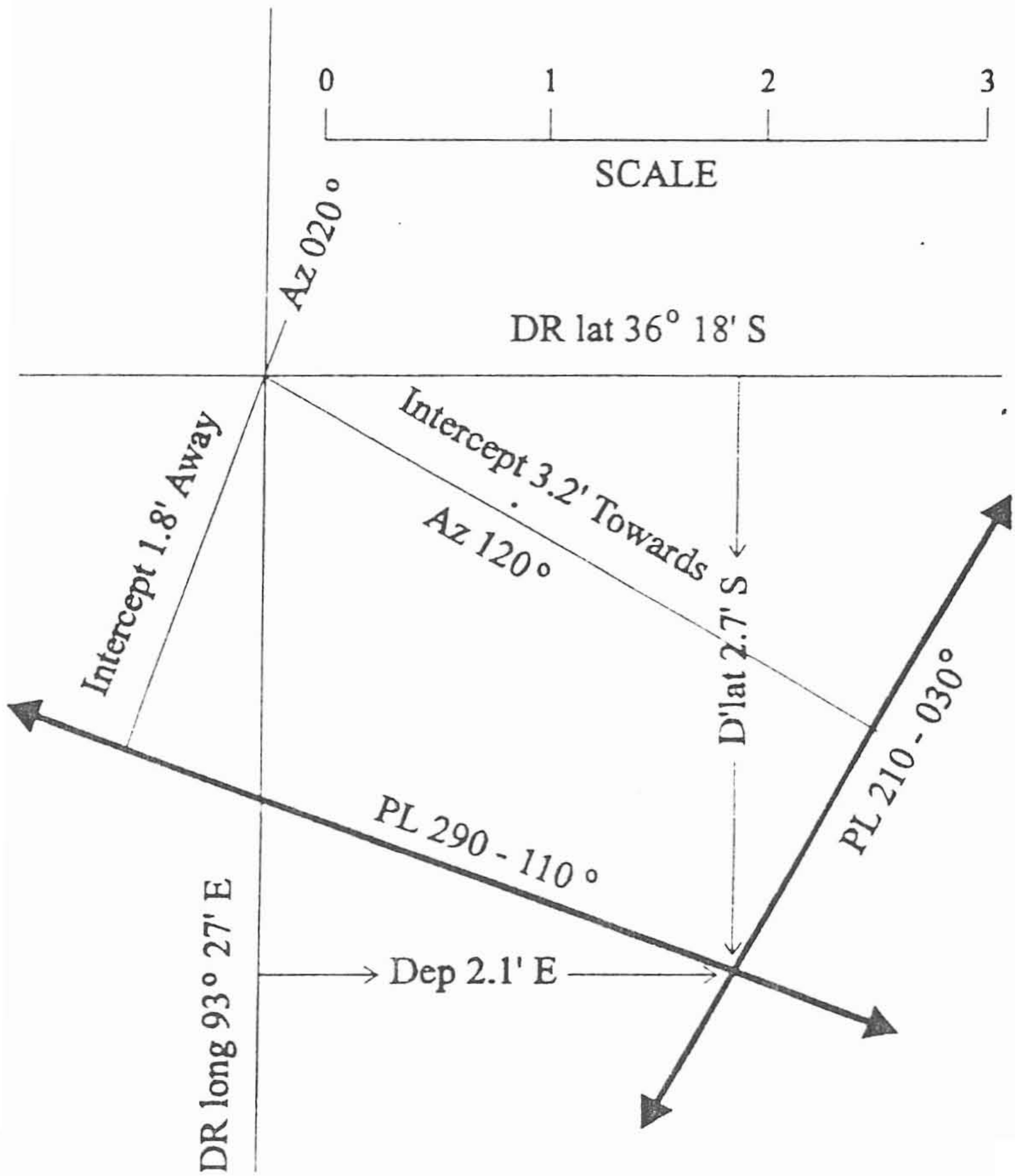


DR lat	20°	36.0'N	long	146°	19.3'W	Using m'lat 20.6°
d'lat	0°	03.0'N	d'long	0°	02.7'E	and dep of 02.5'E
Fix lat	20°	39.0'N	long	146°	16.6'W	d'long is 02.7'E.

A 2 - Two intercepts:-

In DR 36° 18'S 93° 27'E, find the position of the ship using the following observations:-

Intercept 3.2 M Towards Az 120° (T)
Intercept 1.8 M Away from Az 020° (T).



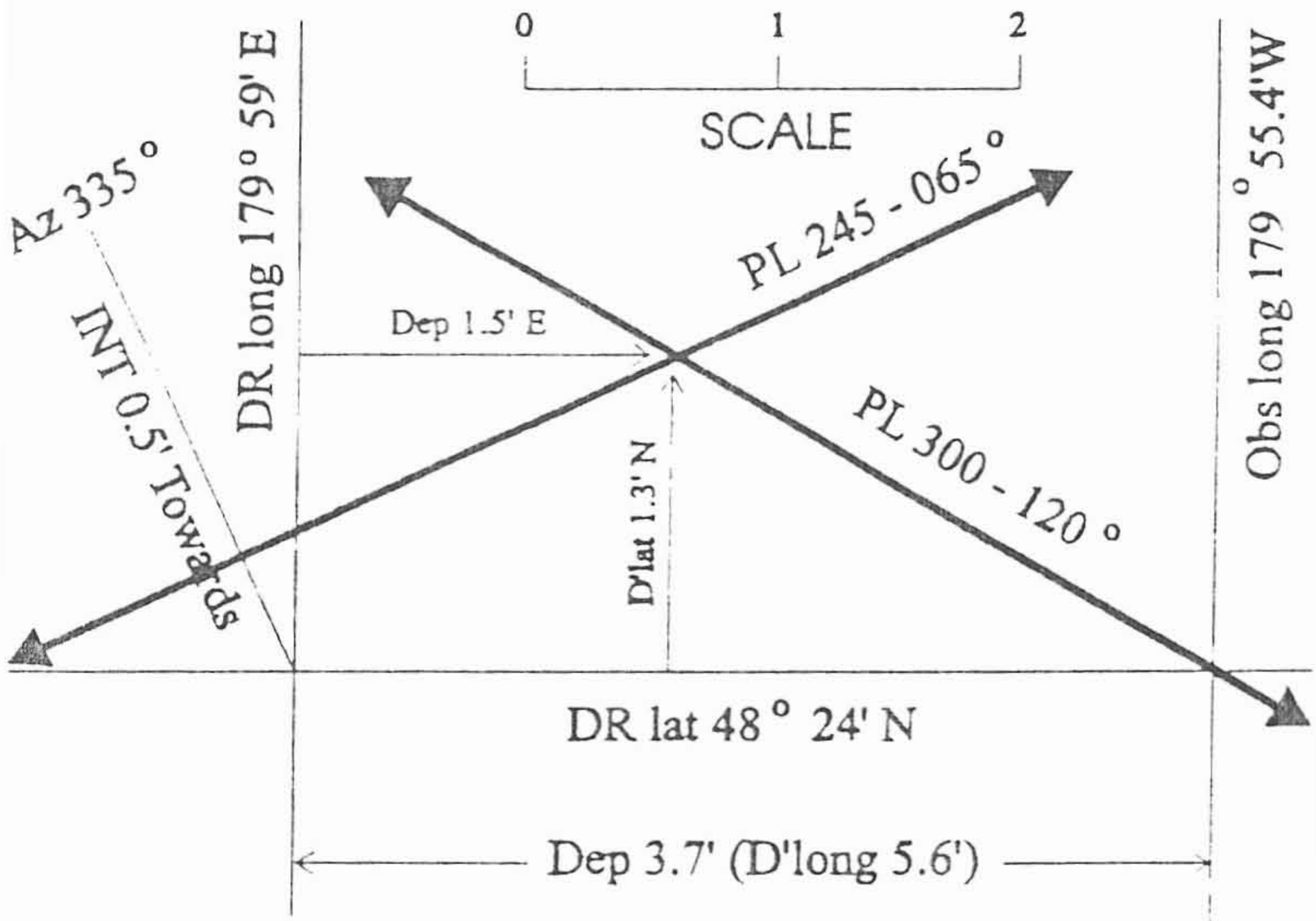
DR	lat	36° 18.0'S	long	093° 27.0'E	Using m'lat 36.3°
	d'lat	0° 02.7'S	d'long	0° 02.6'E	and dep of 02.1'E
Fix	lat	36° 20.7'S	long	093° 29.6'E	d'long is 02.6'E.

A 3 - One long by chron & one intercept:-

In DR 48° 24'N 179° 59'E, find the position of the ship from the following two observations:-

(i) Obs long 179° 55.4'W Az 030° (ii) Int 0.5' Tow Az 335°.

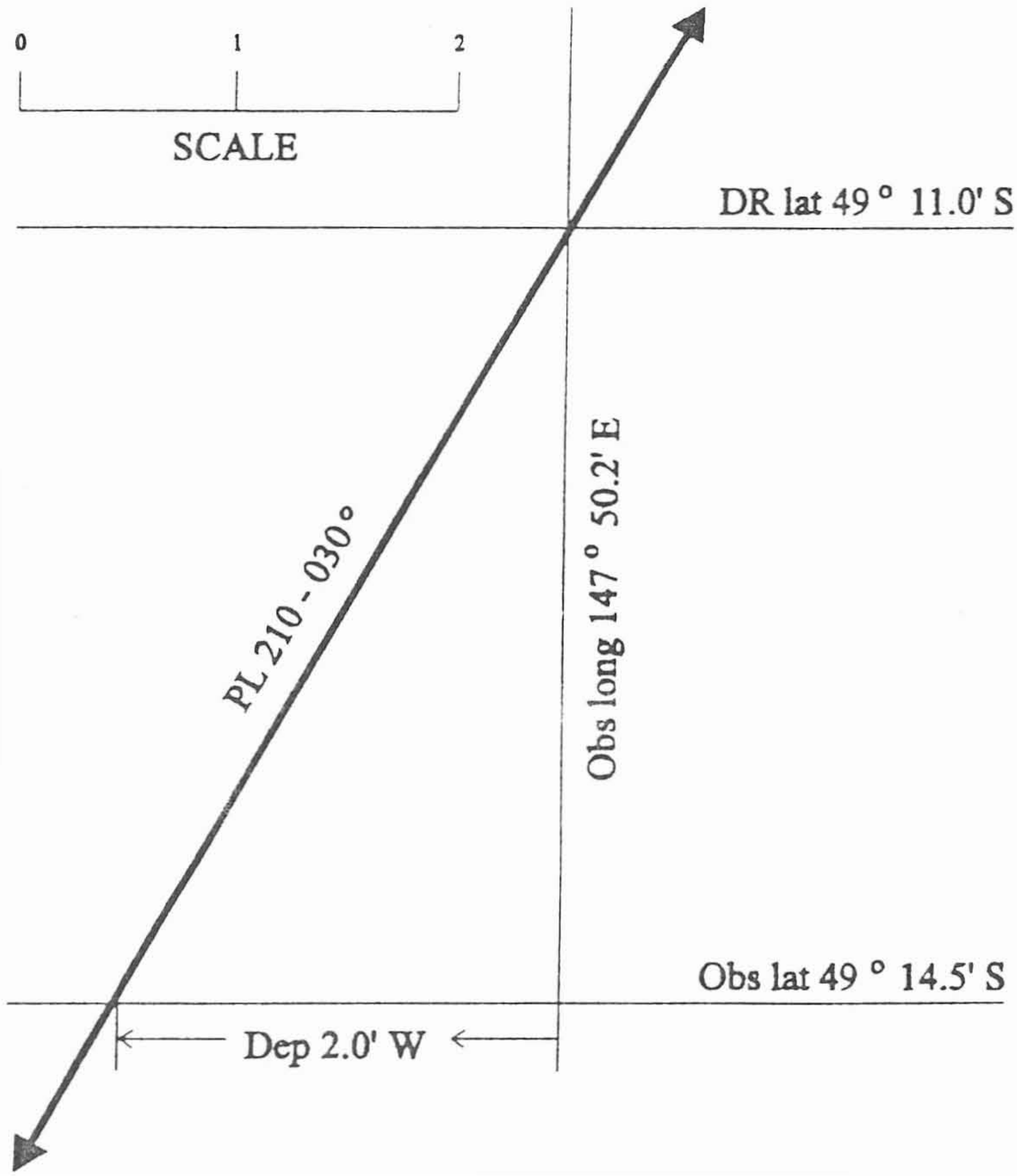
D'long between DR & Obs long = 5.6'. M'lat 48.4°, dep = 3.7'.



DR	lat	48° 24.0'N	long	179° 59.0'E	Using m'lat 48.4°
	d'lat	0° 01.3'N	d'long	0° 02.3'E	and dep of 01.5'E
Fix	lat	48° 25.3'N	long	179° 58.7'W	d'long is 02.3'E.

A 4 - One mer alt and one long by chron:-

In DR 49° 11'S 147° 44'E, an Obs long of 147° 50.2'E and Azimuth of 300° (T) were obtained. A meridian altitude then gave latitude to be 49° 14.5'S. Find the ship's position.



Fix lat 49° 14.5'S	Obs long	147° 50.2'E	Using m'lat 49.2°
	d'long	0° 03.1'W	and dep of 02.0'W
	Fix long	147° 47.1'E	d'long is 03.1'W

Alternative method without plotting:-

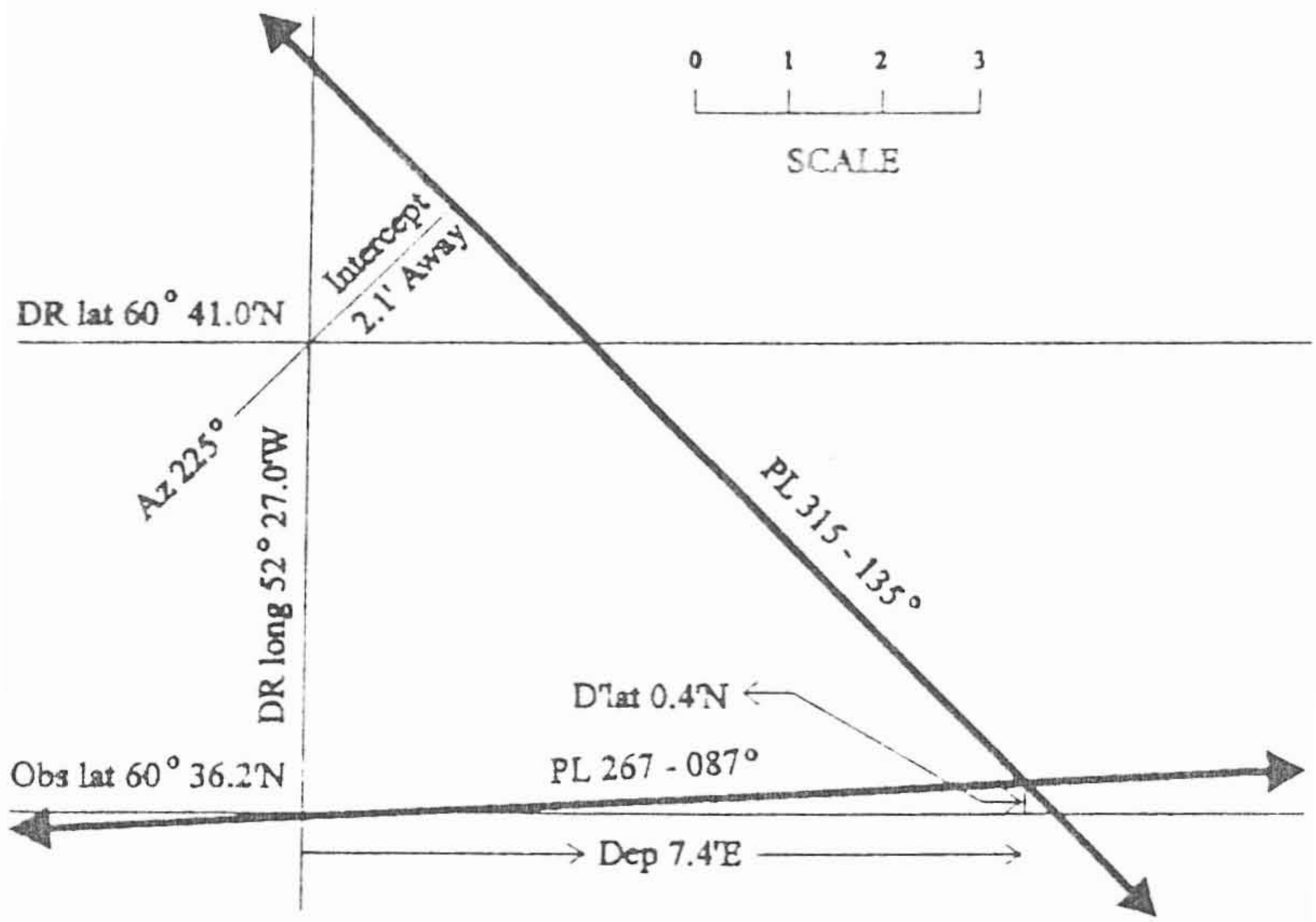
When one PL is exactly E - W, the latitude of the fix is known. The d'lat, from the DR to the fix, multiplied by C correction is the d'long from the DR to the fix.

In this case, d'lat from DR to fix = 3.5'S. From ABC Tables, for lat 49.2° and Az 300°, C = 0.88. D'long = 3.5 x 0.88 = 3.1'. Since PL is 030 - 210°, going S along the PL (d'lat S) also means going W (d'long W). Hence d'long in this case is W.

Long of fix = DR ± d'long = 147° 50.2'E - 3.1'W = 147°47.1'E.

A 5 - One ex-meridian and one intercept:-

In DR 60° 41'N 52° 27'W, an intercept of 2.1' Away from Az 225° was obtained. At the same time, an ex-mer alt gave an Obs lat of 60° 36.2'N and an Az of 357° (T). Find the position of the ship. (Note: This is similar to the combination of an observation of Polaris and an intercept.)

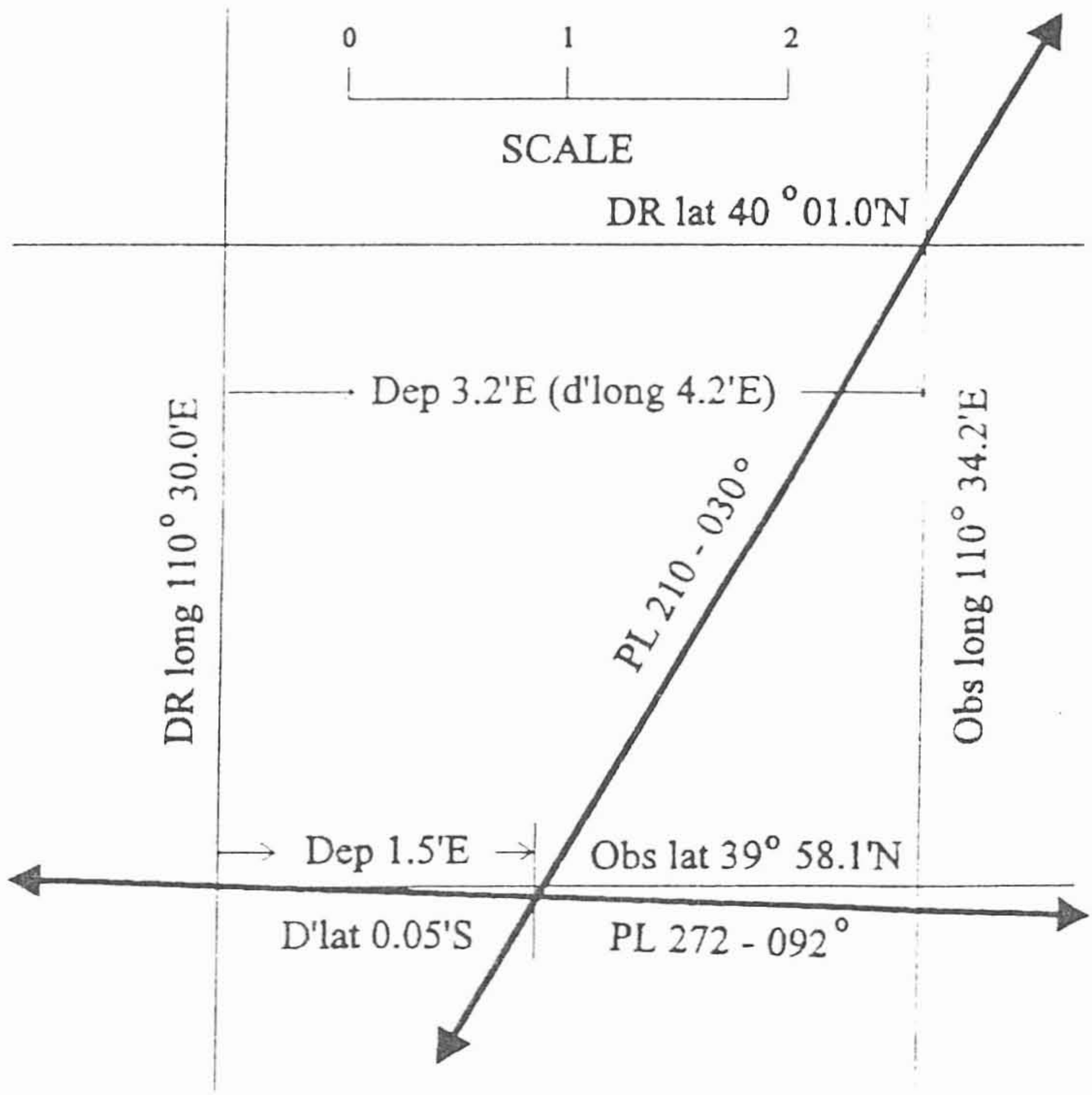


Obs lat	60° 36.2'N	DR long	052° 27.0'W	Using m'lat 60.6°
d'lat	0° 00.4'N	d'long	0° 15.1'E	and dep of 07.4'E
Fix lat	60° 36.6'N	Fix long	052°11.9'W	d'long is 15.1'E.

A 6 - Polaris and one long by chron:-

DR 40° 01'N 110° 30'E. ALDEBARAN - Obs long 110° 34.2'E, Az 120° . Using the same DR, Polaris - Obs lat 39° 58.1'N, bearing 002°(T). Find the ship's position.

M'lat 40.0°, d'long 4.2'E, dep (using T.T.) = 3.2'E.



Obs lat	39° 58.10'N	DR long	110° 30.0'E	Using m'lat 40.0°
d'lat	0° 00.05'S	d'long	0° 02.0'E	and dep of 01.5'E
Fix. lat	39° 58.05'N	Fix long	110°32.0'E	d'long is 02.0'E.

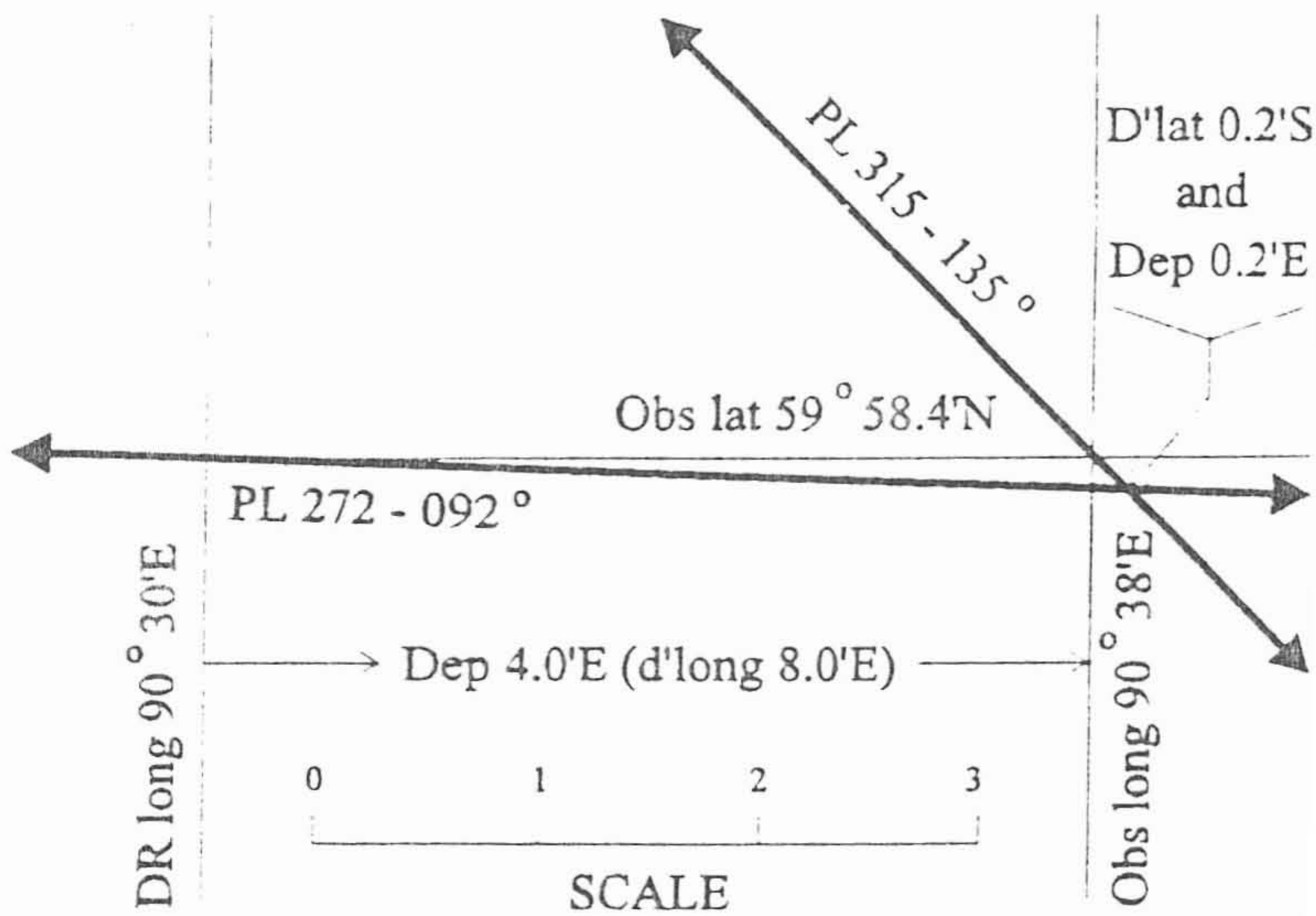
Note: In the foregoing example, it was stated that the same DR was used for working both sights - hence plotting as shown

Plotting would have been simpler if (i) the Obs lat by Polaris/Ex-mer alt was used for calculating the long by chron as shown in example A 7 or (ii) the Obs long obtained was used to calculate the Obs lat by Polaris/Ex-mer alt as shown in example A 8.

A 7 - Polaris and one long by chron:-

Using DR 60° 00'N 90° 30'E, star Polaris gave an Obs lat of 59° 58.4'N bearing 002°(T). With this Obs lat, star BETELGEUSE gave an Obs long of 90° 38'E and an Az of 045°. Find the position of the ship.

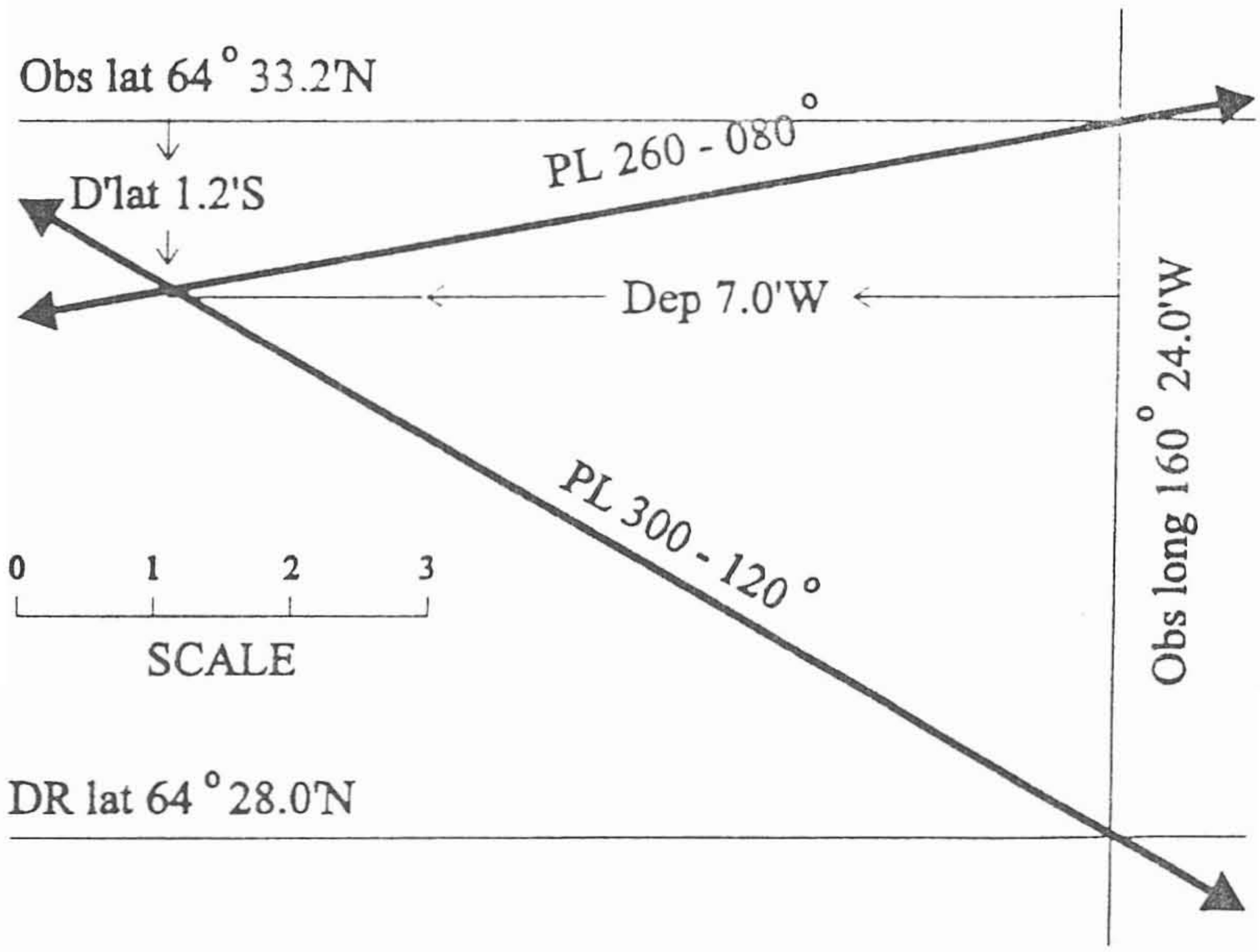
M'lat 60.0°, d'long 8.0'E, dep (using T.T.) = 4.0'E.



Obs lat	59° 58.4'N	Obs long	090°38.0'E	Using m'lat 60.0°
d'lat	0° 00.2'S	d'long	0° 00.4'E	and dep of 00.2'E
Fix lat	59° 58.2'N	Fix long	090°38.4'E	d'long is 00.4'E.

A 8 - Polaris and one long by chron:-

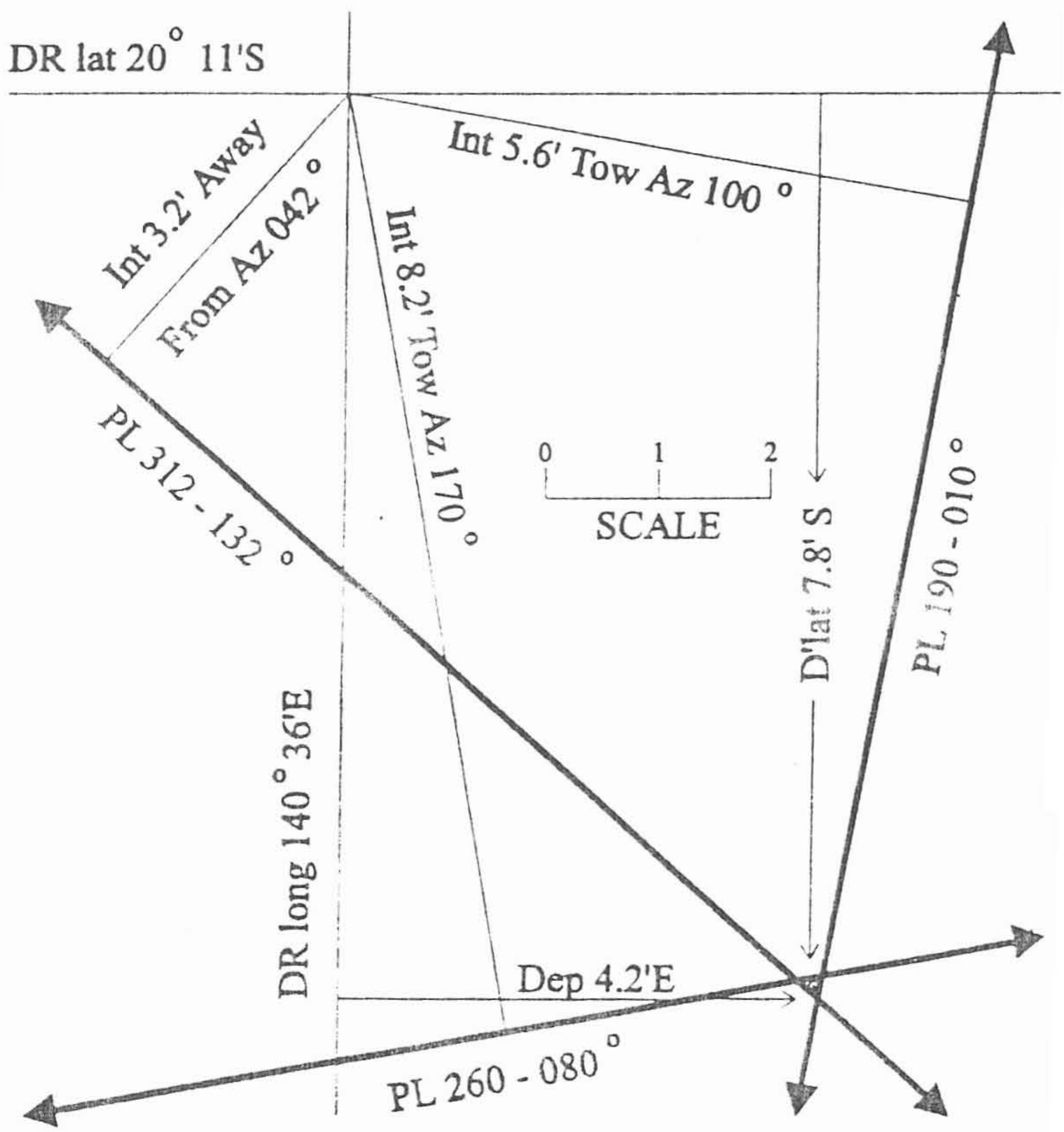
While a ship was In DR position 64° 28'N 160° 20'W, an observation of the star RIGEL gave an Observed longitude of 160° 24'W on a bearing of 210° (T). Very soon thereafter, using this Observed longitude, an ex-meridian observation of the star VEGA gave an Observed latitude of 64° 33.2'N with an Azimuth of 350° (T). Find the position of the ship by graphical combination of these two observations.



Obs lat	64° 33.2'N	Obs long	160° 24.0'W	Using m'lat 64.5°
d'lat	0° 01.2'S	d'long	0° 16.3'W	and dep of 07.0'W
Fix lat	64° 32.0'N	Fix long	160° 40.3'W	d'long is 16.3' W.

A 9 - Three intercepts:-

A ship in DR 20° 11'S 140° 36'E obtained the following intercepts:- (a) 3.20 M Away from Azimuth 042° (T) (b) 5.6M Towards Az 100°(T) & (c) 8.2M Towards Az 170°(T). Find the position of the ship.



DR lat	20° 11.0'S	DR long	140° 36.0'E	Using m'lat 20.3°
d'lat	0° 07.8'S	d'long	0° 04.5'E	and dep of 04.2'E
Fix lat	20° 18.8'S	Fix long	140° 40.5'E	d'long is 04.5'E.

Note: This is the usual method of obtaining a star fix at sea. The triangle formed by the intersection of the three position lines is called the 'Cocked hat'. When sights are taken properly, the cocked hat would be very small. Common causes of a large cocked hat are:

(a) Error in observation of altitude or time by the observer.
(b) Too much interval between sights, during which the ship's run is ignored.
(c) Small angle of cut between position lines. For good angle of cut, using three stars, they should be around 45° - 60° apart.

When the cocked is small, the position of the ship is taken to be at the centre. The position of the ship cannot be obtained directly from the plot if the cocked hat is large.

Three intercepts are easier to plot than three longitudes by chronometer.

A 10 - Three longitudes by chronometer:

From the following observations in DR 15° 02'N 75° 39'W, find the position of the vessel:-

(a) Obs long 075° 42.7'W - Az 331° (T)
(b) Obs long 075° 38.1'W - Az 115° (T)
(c) Obs long 075° 32.8'W - Az 227° (T).

Obs long	075° 42.7'W	Obs long	075° 38.1'W
Obs long	075° 38.1'W	Obs long	075° 32.8'W
d'long	04.6'E	d'long	05.3'E
dep	04.4'E	dep	05.1'E (m'lat 15.0°)

From the plotted figure on the next page:-

DR lat	15° 02.0'N	Obs long	075° 38.1'W	Using m'lat 15.1°
d'lat	0° 03.5'N	d'long	0° 01.9'E	and dep of 01.8'E
Fix lat	15° 05.5'N	Fix long	075°36.2'W	d'long is 01.9'E.

By the scale drawing on the previous page, the fix lies 3M East of the 1150 Obs long. Using m'lat of 45.8° and dep of 3'E, d'long is found = 4.3'E. Fix long = 117° 35.6'E + 4.3'E = 117° 39.9'E.

Run 1150 to 1200 at 15 knots = 2.5 miles on course of S58°W.

1150 Fix lat	45° 51.2'N	Fix long	117° 39.9'E	m'lat of 45.8°
Run d'lat	0° 01.3'S	d'long	0° 03.0'W	dep of 02.1'W
1200 EP lat	45° 49.9'N	EP long	117° 36.9'E	d'long = 3.0'

Alternative method without plotting:-

When one PL is exactly E - W, the latitude of the fix is known. The d'lat, from the DR lat to the fix, multiplied by C correction is the d'long from the DR to the fix.
In this case, d'lat from DR to fix = 1.7'N. From ABC Tables, for lat 46.3° and Az 150°, C = 2.50. D'long = 1.7 x 2.50 = 4.3'. Since PL is 060 - 240°, going N along the PL (d'lat N) also means going E (d'long E). Hence d'long in this case is E.

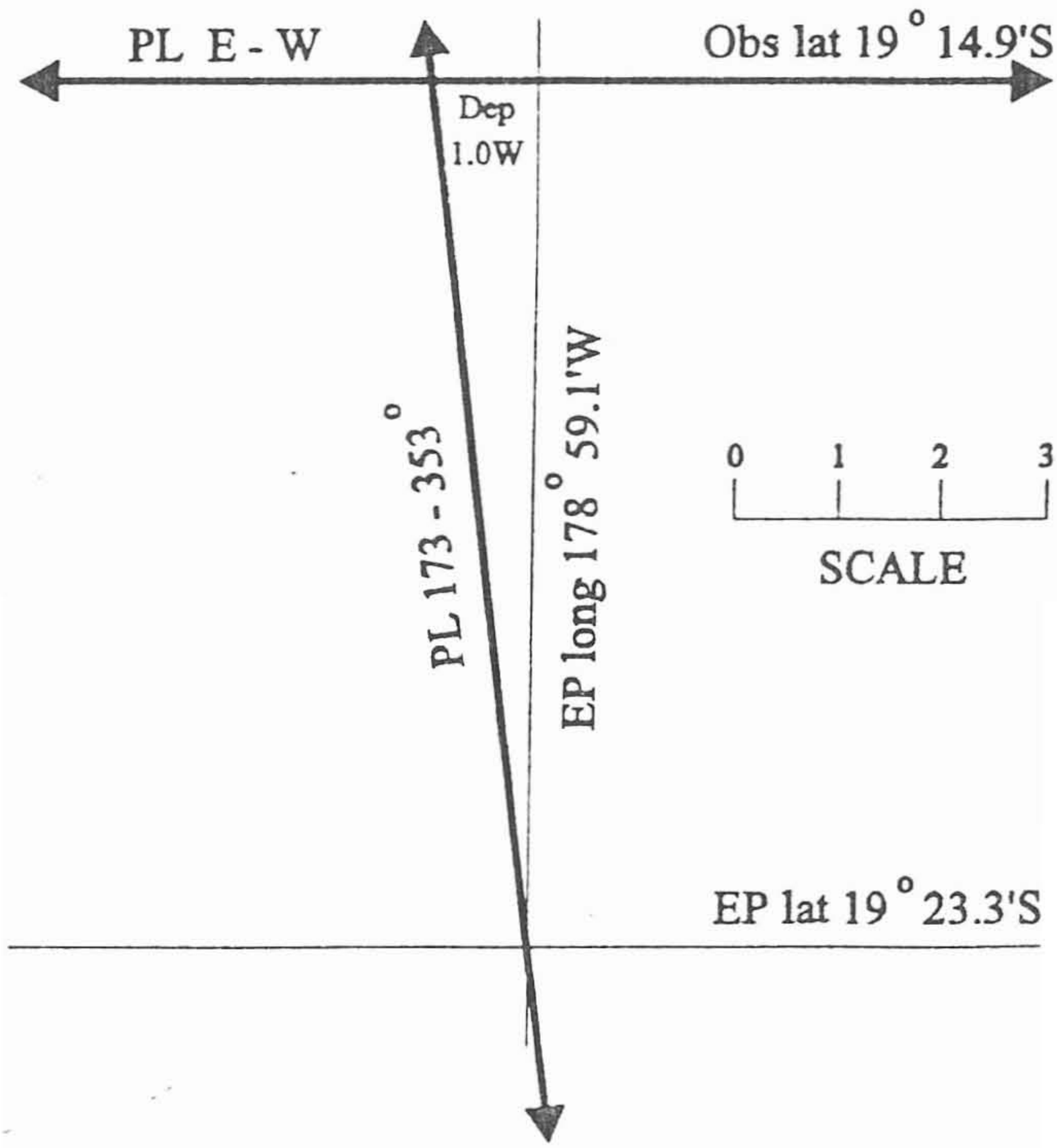
Long of fix = DR ± d'long = 117° 35.6'E + 4.3'E = 117° 39.9'E.

B 2:- In DR 18° 41'S 179° 56'E an intercept of 8.4' towards Az 083°(T) was obtained by stellar observation. The vessel then steered 121° (T) for 70M by log when a meridian altitude gave an Obs lat of 19° 14.9'S. If a set of 224°(T) and a drift of 10M was experienced during the interval, find the position of the vessel at the second observation.

Note: To the DR position, allow the run to the ITP (intercept terminal point) - if intercept is towards, allow Az as course and if intercept is away, allow Az + 180° as course. Then allow for the courses and distances steamed and also for the set and drift of current like day's work. The position so obtained would be the position to transfer the PL (arrival EP).

Course (T)	Dist M	d'lat N	d'lat S	dep E	dep W
083° = N83°E	08.4	01.0		08.3	
121° = S59°E	70.0		36.1	60.0	
224° = S44°W	10.0		07.2		06.9
Total		01.0	43.3	68.3	06.9
			01.0	06.9	
Resultant			42.3	61.4	

DR lat	18° 41.0'S	DR long	179° 56.0'E	Using m'lat 19.0°
d'lat	0° 42.3'S	d'long	1° 04.9'E	and dep of 61.4'E
EP lat	19° 23.3'S	EP long	178° 59.1'W	d'long is 64.9'E.



Using dep 1.0'W (by plotting) & m'lat of 19.3° d'long = 1.1'W
Long of fix = EP ± d'long = 178° 59.1W + 1.1'W = 179° 00.2W.

Alternative method without plotting:-

When one PL is exactly E - W, the latitude of the fix is known. The d'lat, from the DR lat to the fix, multiplied by C correction is the d'long from the DR to the fix.
In this case, d'lat from EP to fix = 8.4'N. From ABC Tables, for lat 18.7° and Az 083°, C = 0.13. D'long = 8.4 x 0.13 = 1.1'.
Since PL is 173 - 353°, going N along the PL (d'lat N) also means going W (d'long W). Hence d'long in this case is W.

Long of fix = EP ± d'long = 178° 59.1'W + 1.1W = 179° 00.2W.

B 3:- At 0600 in DR 01° 20'N 179° 58'W, a stellar observation gave an Obs long of 179° 54'E bearing 062°(T). The vessel then steamed 131°(T) at 14 knots. At 1600, using lat 00° 11.8'S, the Sun gave an Obs long of 178° 12.7'W bearing 323°(T). Find the position of the vessel at 1600.

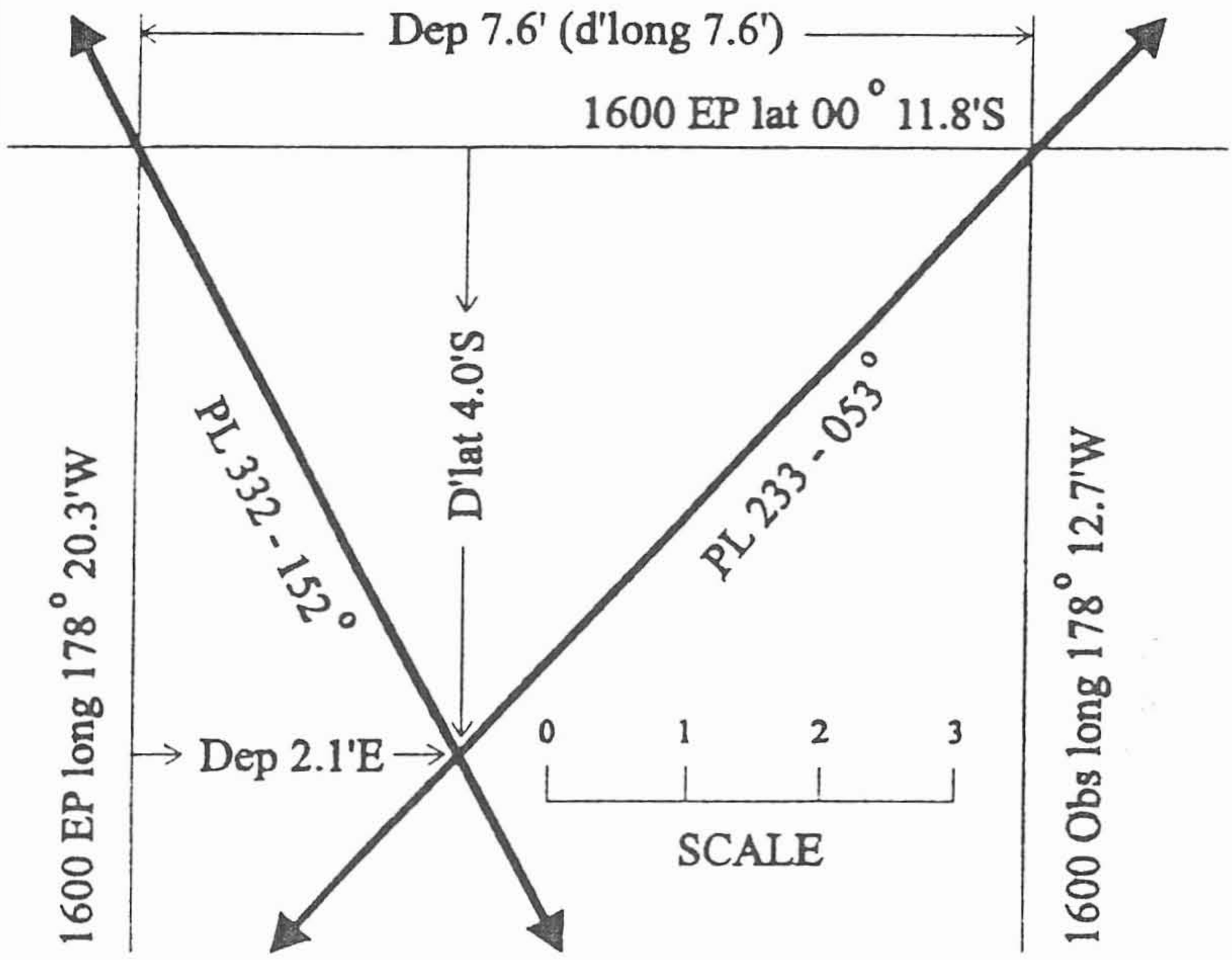
Co S49°E and distance 140M, d'lat = 91.8'S and dep = 105.7'E

0600 DR lat	01° 20.0'N	Obs long	179° 54.0'E	m'lat of 00.6°
Run d'lat	01° 31.8'S	d'long	1° 45.7'E	dep = 105.7'E
1600 EP lat	00° 11.8'S	EP long	178° 20.3'W	d'long 105.7E
		Obs long	178° 12.7'W	
		d'long	07.6'E	

Since EP lat is only 0.2°, dep = d'long = 07.6'E.

From the plot on the next page:-

1600 EP lat	00° 11.8'S	EP long	178° 20.3'W	m'lat of 00.2°
d'lat	00° 04.0'S	d'long	0° 02.1'E	dep of 02.1'E
1600 Fix lat	00° 15.8'S	Fix long	178° 18.2'W	d'long is 02.1E



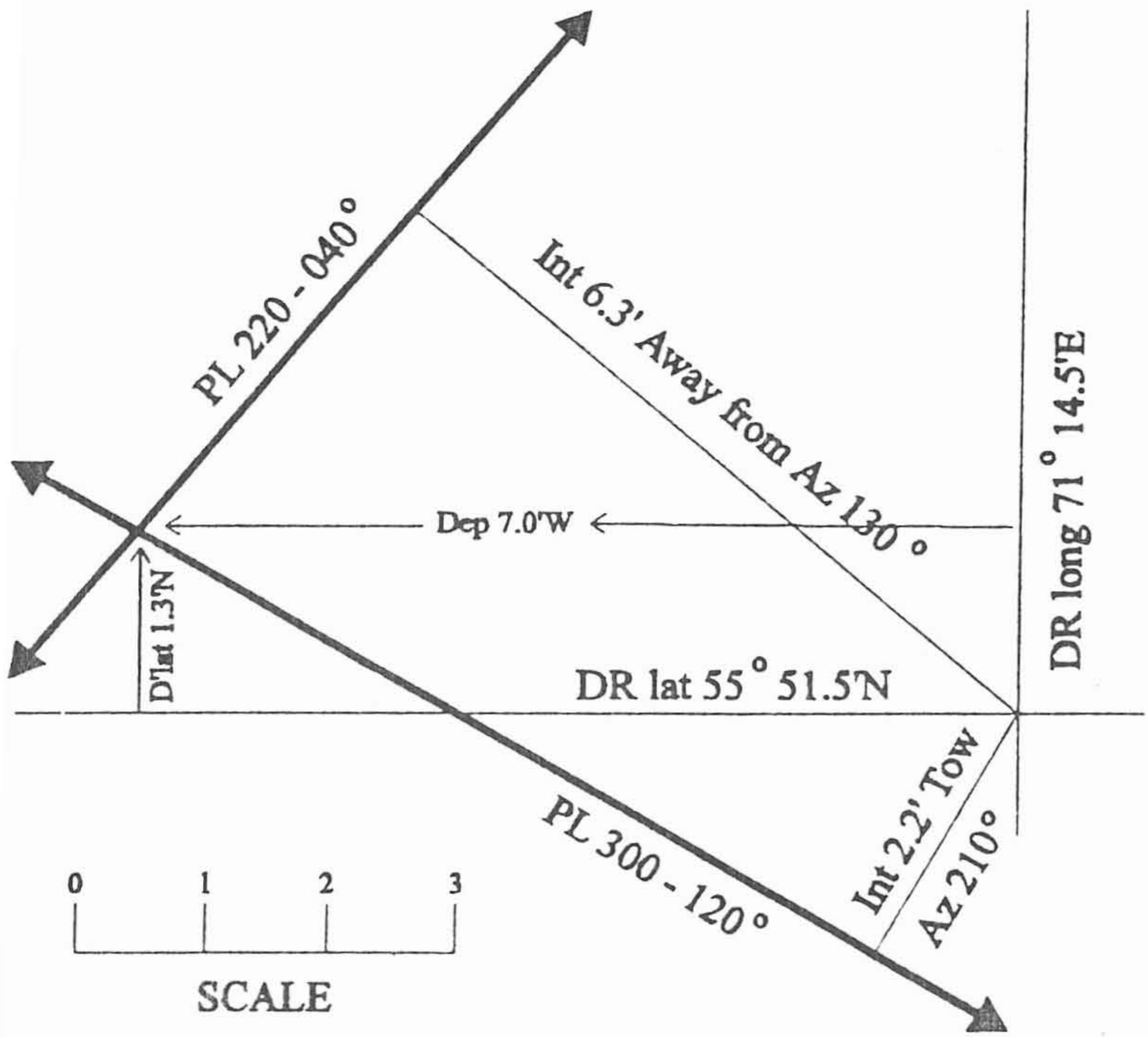
B 4:- In DR 56° 11'N 72° 23'E, an intercept of 6.3' away from Az 130°(T) was obtained by an astronomical observation. Ship then steamed 243°(T) for 43 miles when another astronomical observation gave an intercept of 2.2' towards Az 210°(T). The DR used for the second observation was obtained directly by allowing the run to the first DR. Find the position of the ship at the second observation.

Co 243° = S63°W, distance 43M, d'lat = 19.5'S & dep = 38.3'W

First DR lat	56° 11.0'N	DR long	072° 23.0'E	m'lat of 56.0°
Run d'lat	00° 19.5'S	d'long	1° 08.5'W	dep of 38.3'W
2nd DR lat	55° 51.5'N	DR long	071° 14.5'E	d'long = 68.5W

From the plot on the next page:

2nd DR lat	55° 51.5'N	DR long	071° 14.5'E	m'lat of 55.9°
Run d'lat	00° 01.3'N	d'long	0° 12.5'W	dep of 07.0'W
Fix lat	55° 52.8'N	Fix long	071° 02.0'E	d'long = 12.5W

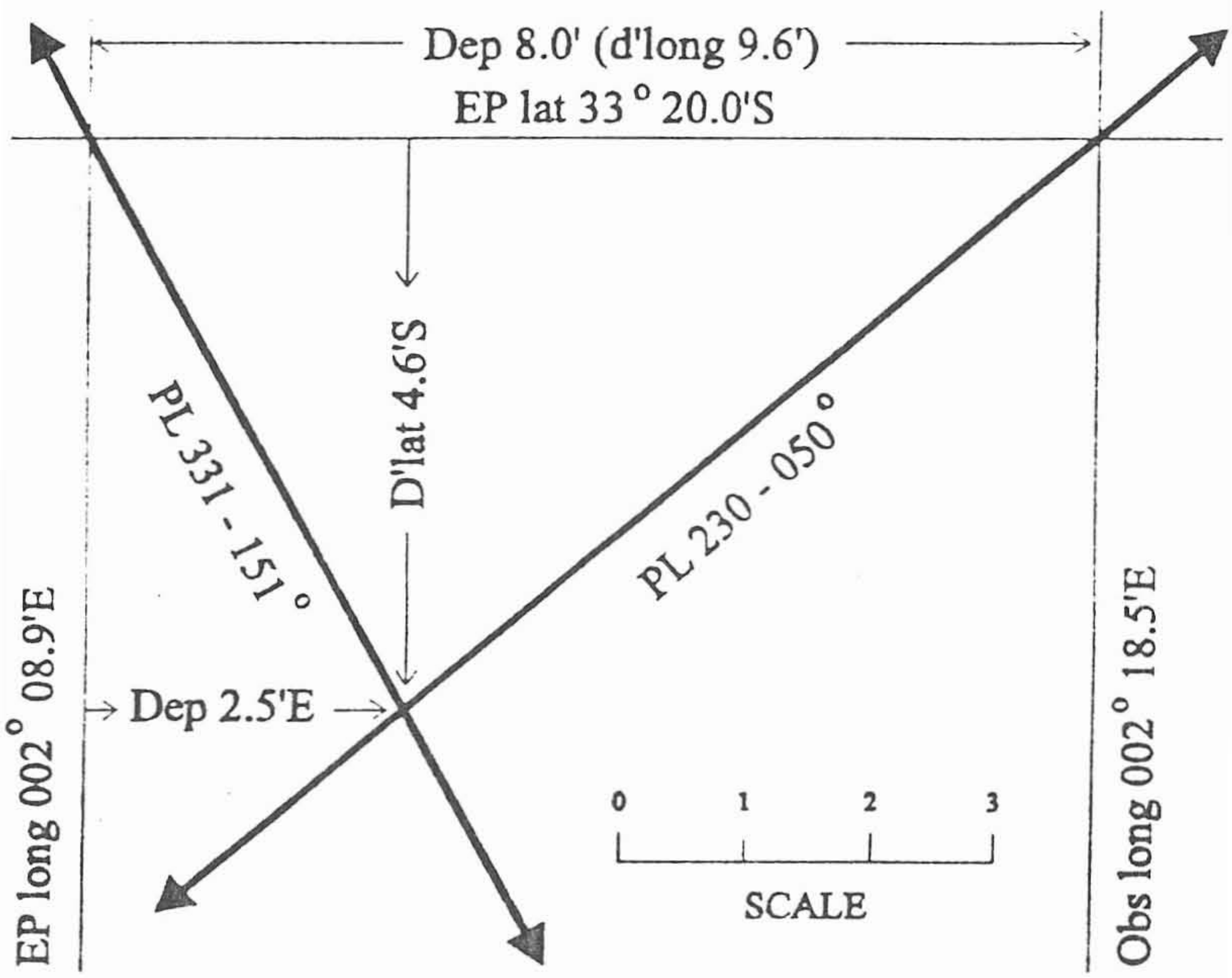


B 5:- In DR 33° 18'S 000° 12.6'W, a stellar observation gave an intercept of 4.2' towards Az 241°(T). After steaming 090°(T) for 122M, another astronomical observation gave an Obs long of 002° 18.5'E bearing 140°(T). The EP used for working the second observation was obtained through the first ITP. Find the position of the ship at the second observation.

Intercept is towards so course = azimuth = 241° = S61°W.

Course (T)	Dist	N d'lat S	E dep W
241° = S61°W	004.2	2.0	3.7
090° = N90°E	122.0		122.0
Total		2.0	122.0 3.7
		0.0	3.7
Resultant		2.0	118.3

DR lat	33° 18.0'S	DR long	000° 12.6'W	Using m'lat 33.3°
Res d'lat	0° 02.0'S	d'long	02° 21.5'E	& dep of 118.3'E
EP lat	33° 20.0'S	EP long	02° 08.9'E	d'long is 141.5'E.
		Obs long	02° 18.5'E	Using m'lat 33.3°
		d'long	09.6'E	dep = 8.0'E.

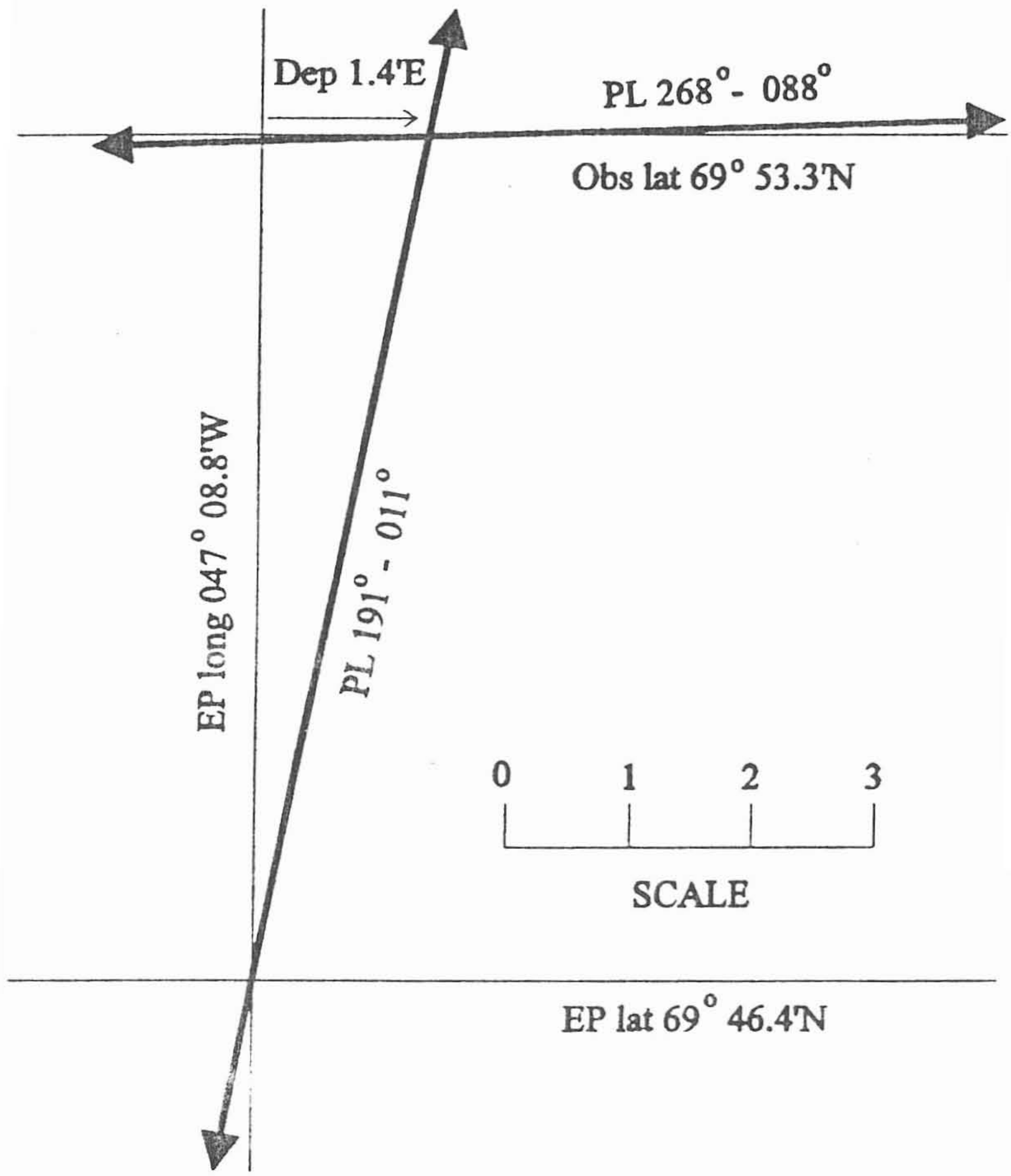


EP lat	33° 20.0'S	EP long	002° 08.9'E	Using m'lat 33.4°
d'lat	0° 04.6'S	d'long	0° 03.0'E	and dep of 02.5'E
Fix lat	33° 24.6'S	Fix long	002° 11.9'E	d'long is 03.0'E.

B 6:- In DR 68° 12.5'N 44° 18'W an astronomical observation gave an Obs long of 44° 10.6'W whilst bearing 281°(T). After steaming for 112 M on a course of 327°(T), an observation of Polaris gave Obs lat 69° 53.3'N bearing 358°(T), using EP long worked from the earlier Obs long. Find the position of the ship at the second observation.

Course = 327° = N33°W, distance = 112 M.

DR lat	68° 12.5'N	Obs long	044° 10.6'W	Using m'lat 69.0°
d'lat	1° 33.9'N	d'long	2° 50.2'W	and dep of 61.0'W
EP lat	69° 46.4'N	EP long	047° 00.8'W	d'long is 170.2'W

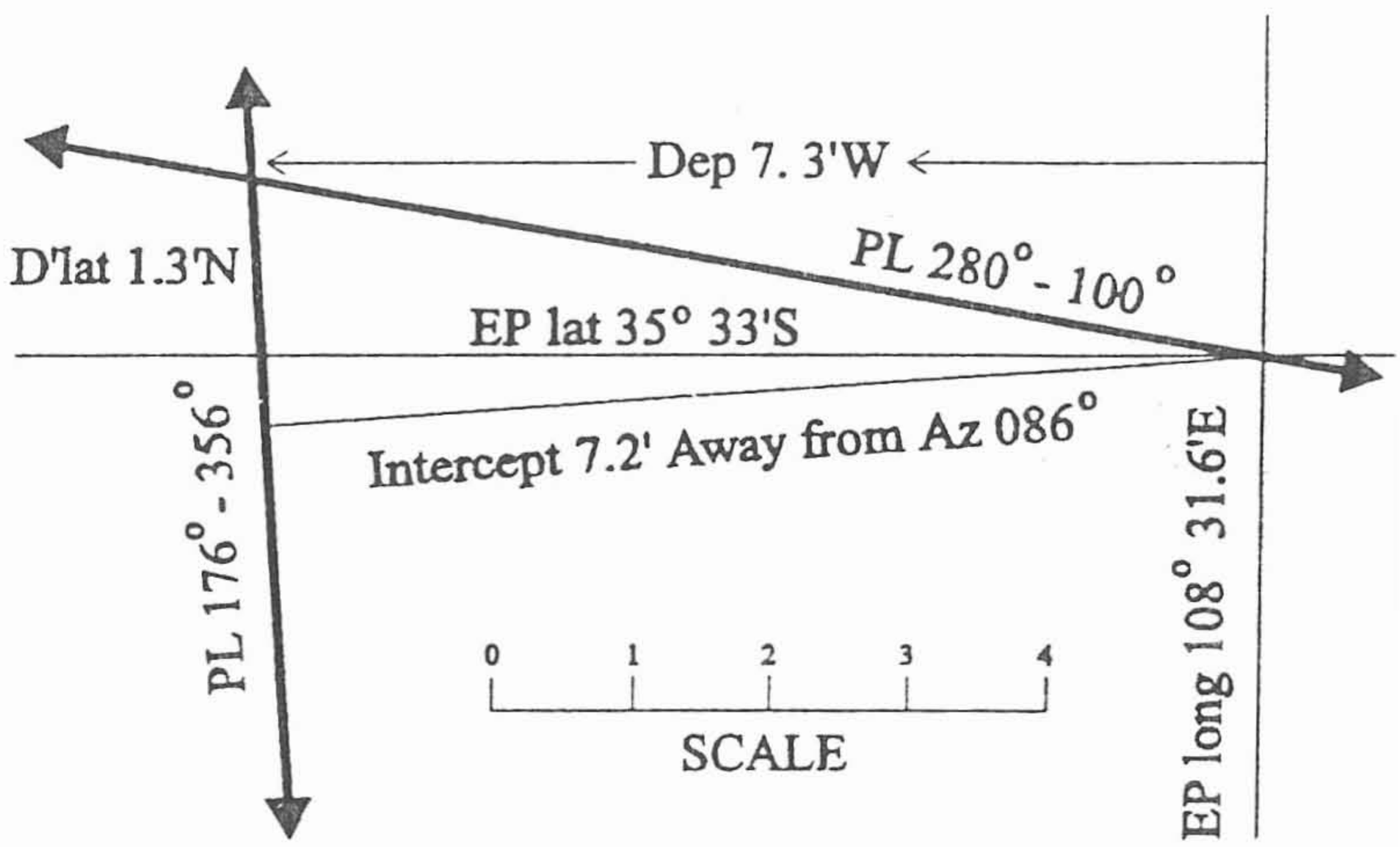


Obs lat	69° 53.3'N	EP long	047° 00.8'W	Using m'lat 69.9°
d'lat	0° 00.0'N	d'long	0° 04.1'E	and dep of 01.4'E
Fix lat	69° 53.3'N	Fix long	046° 56.7'W	d'long is 04.1'E

B 7:- In DR 36° 48'S 110° 37'E, an Ex-meridian sight gave an Obs Lat of 37° 00'S and a PL of 100° - 280°(T). After steaming 000°(T) for 87 M and 270°(T) for 101 M, an intercept of 7.2 M Away from Az 086°(T) was obtained working from the earlier Obs lat. Find the position of the ship at the second observation.

Course (T)	Dist M	d'lat N	d'lat S	dep E	dep W
N	87.0	87.0			
W	101.0				101.0
Total & resultant		87.0			101.0

Obs lat	37° 00.0'S	DR long	110° 37.0'E	Using m'lat 36.3°
d'lat	01° 27.0'N	d'long	002° 05.4'W	and dep of 101'W
EP lat	35° 33.0'S	EP long	108° 31.6'E	d'long is 125.4'W



EP lat	35° 33.0'S	EP long	108° 31.6'E	Using m'lat 35.5°
d'lat	00° 01.3'N	d'long	000° 09.0'W	and dep of 07.3'W
Fix lat	35° 31.7'S	Fix long	108° 22.6'E	d'long is 09.0'W.

-o0o-

19

CORRECTION OF SIMPLE ERRORS IN SIGHTS

While taking sights and calculating the results thereof, there are a few errors that may sometimes creep in. If detected early, there is no difficulty. If detected at a late stage in the calculation, reworking the entire calculation using the correct inputs is one possible way of setting matters right but this may prove tedious and time consuming. In many cases, it may be easier to assess the value of the consequent error in the result and apply this value as a correction to the incorrect result.

The errors in inputs may be divided into two classes -
1. Those that affect true altitude and
2. Those that affect hour angle.

1. Errors that affect the true altitude:

These generally consist of error in reading the sextant, wrong value or sign of index error, incorrect height of eye, wrong value of total correction, clerical error (incorrect totalling), etc whereby the true altitude obtained is in error.

After studying Chapter 13, it is apparent that:

If the true altitude has to be increased, by say 2.3', the Zenith Distance has to be DECREASED by the same amount, i.e., is 2.3'. The position line already obtained has to be shifted TOWARDS the azimuth by the same amount, i.e., 2.3'.

If the true altitude has to be decreased, by say 3.1', the Zenith Distance has to be INCREASED by the same amount, i.e., 3.1'. The position line already obtained has to be shifted AWAY from the azimuth by the same amount.

The shifting of the PL, as stated above, can be done by direct calculation or by simple plotting depending on the circumstances, as illustrated in the following worked examples.

Worked example 1 - Intercept

Using DR 44° 36'N 89° 23'E, a celestial observation gave an intercept of 1.7' Towards Az 130°(T). It was subsequently discovered that IE of 2.4' ON the arc had been applied as OFF the arc. Find the new intercept.

If the error had NOT been applied at all, the true altitude must be decreased by 2.4'. Since it was applied the other way - added instead of subtracted - the true altitude has to be decreased, and hence the Zenith Distance increased, by 4.8'. Increasing ZD by 4.8' means going away from the GP of the body. An intercept correction of 4.8' AWAY has to be applied to the intercept already obtained.

Intercept already obtained:	1.7' Towards
Correction to be applied:	4.8' Away
Correct Intercept from DR:	3.1' Away from Az 130°(T)

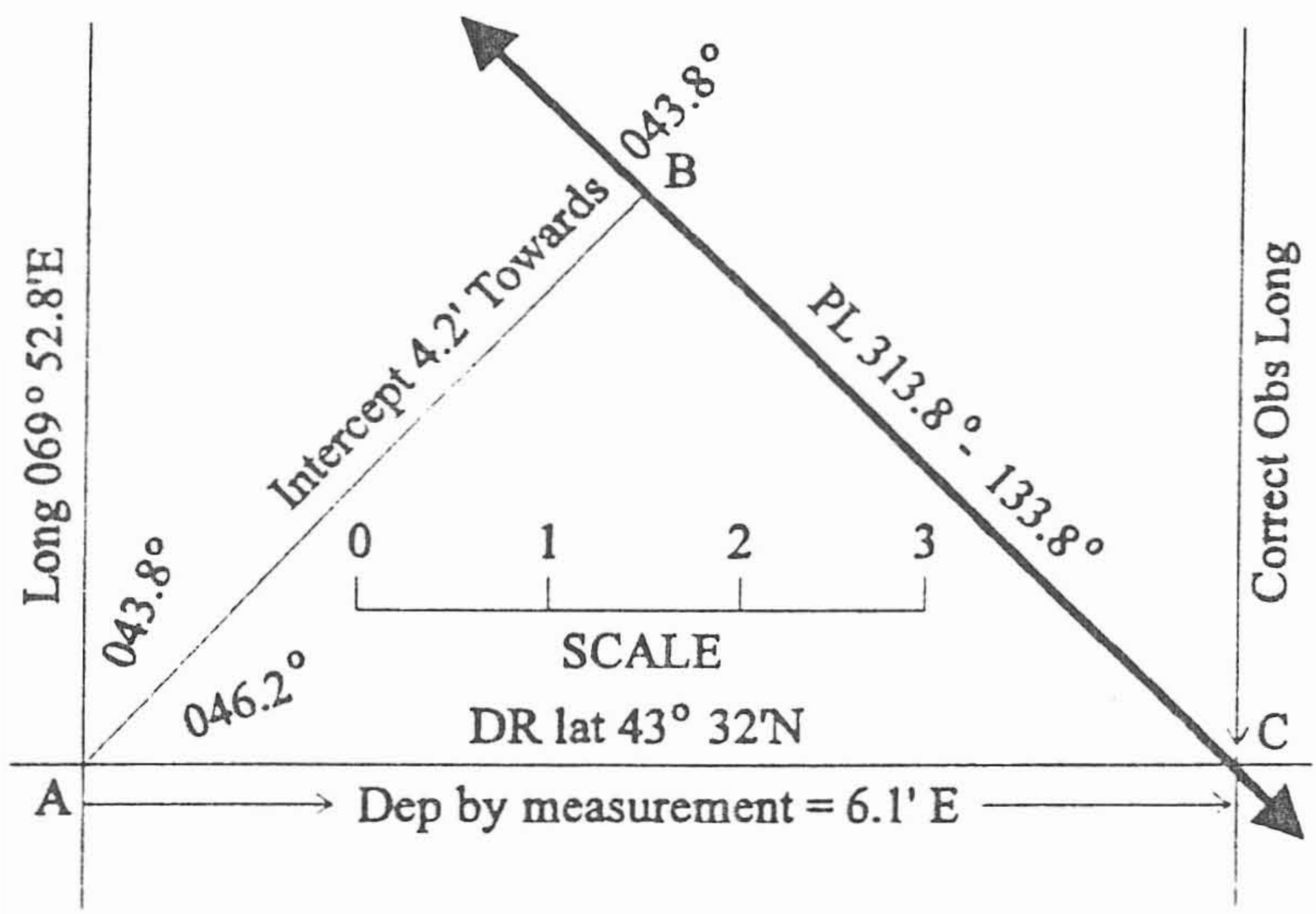
Worked example 2 - Long by chron.

Using DR 43° 32'N an Obs long of 69° 52.8'E and an Az of 043.8° (T) was obtained. It was found later on that the HE used for the calculation was taken as 40 m instead of 14 m. Find where the PL should be drawn.

Dip for 40 m = 11.1' and for 14 m = 6.6'. Difference = 4.5'. The true altitude has to be increased, and hence the ZD has to be decreased, by 4.5'. The PL has to be shifted Towards Az by 4.5'.

Hence it can be stated that an intercept of 4.5' Towards Az 043.8°(T) has to be applied from position 43° 32'N 69° 52.8'E and PL 133.8° - 313.8°(T) has to be drawn from the ITP. This is sufficient for actual use at sea.

If, for any reason, it is desired to know the actual value of the correct Obs long, it can be obtained by a simple plot drawn to scale or by a simple calculation.



By measurement, departure on the foregoing plot to scale = 6.1'E.

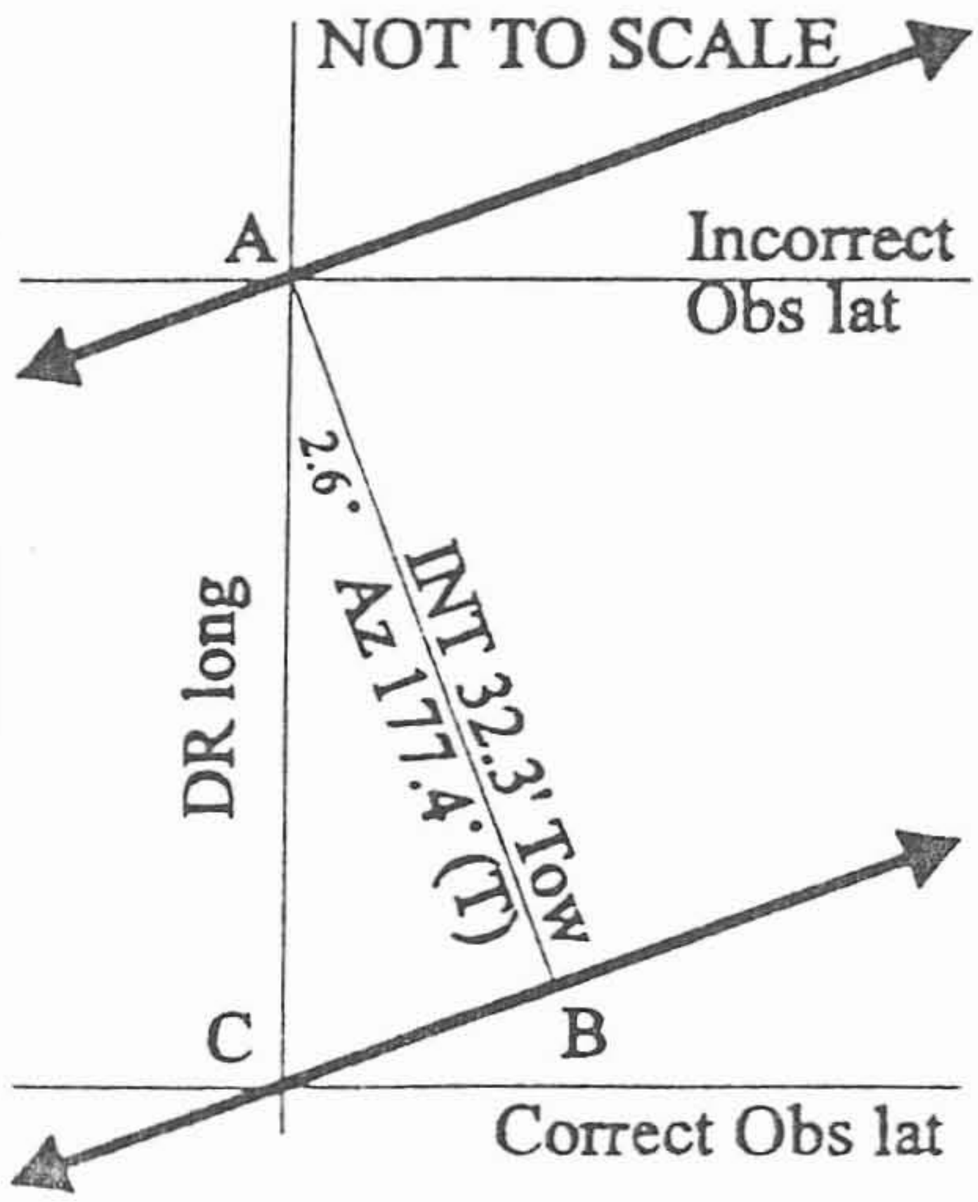
By calculation, in Δ ABC, AC = dep = 4.2 x Sec 46.2° = 6.1'E.
(For calculation purposes, a rough sketch would be sufficient).
D'long = Dep x Secant lat = 6.1 x Sec 43° 32' = 08.4'E.
Correct Obs long = 69° 52.8'E + 0° 08.4'E = 70° 01.2'E

Worked example 3 - Ex-meridian

An ex-meridian alt of the Sun gave Obs lat 43° 12'N DR long 63° 29'W Az 177.4°(T). It was then found that the UL (correction -18.2') had been used in the calculation instead of LL (correction +14.1'). State where the PL should be drawn.

Altitude correction applied already ..... = - 18.2'
Altitude correction that should have been applied = + 14.1'
Correction to apply to incorrect T.alt obtained = + 32.3'

The ZD obtained should be decreased by 32.3' so an intercept of 32.3' Towards Az 177.4°(T) has to be applied.



If it is desired to know the correct Obs lat, a simple calculation is necessary. The intercept of 32.3 M is too great a distance for accurate results by plotting to scale.

D'lat AC = AB x Sec 2.6° = 32.3 x Sec 2.6° = 32.3'S
Correct Obs lat = 43° 12' - 00° 32.3' = 42° 39.7'N

2. Errors that affect hour angle:

These generally consist of error in reading the chronometer, wrong value or sign of chronometer error, incorrect date of GMT, incorrect reading of GHA/increment from Almanac, etc. incorrect totalling (clerical error) whereby the GHA obtained is in error. If the working is long by chron, the correct GHA can be applied to the LHA and the correct Obs long obtained easily. If the working is an intercept, a little thought is necessary as illustrated by the following worked examples.

Worked example 4 - Long by chron

Using lat 20° 46'S, an observation of the Sun gave an Obs long of 119° 17.8'W and an Az of 201°(T). It was later found that chron error of 2m 24s slow had not been applied. Find where the PL should be drawn.

Since slow error is additive, the GMT has to be increased by 2m 24s. From the Almanac, increment for the GHA of the Sun for 2m 24s = 36.0'. This means that the GHA has to be increased by 36.0'.

Since long is W, GHA - LHA = Obs long.
Increase of GHA, in this case, would increase Obs long by 36.0'.

Correct Obs long = 119° 17.8'W + 000° 36.0'W = 119° 53.8'W.

Worked example 5 - Intercept

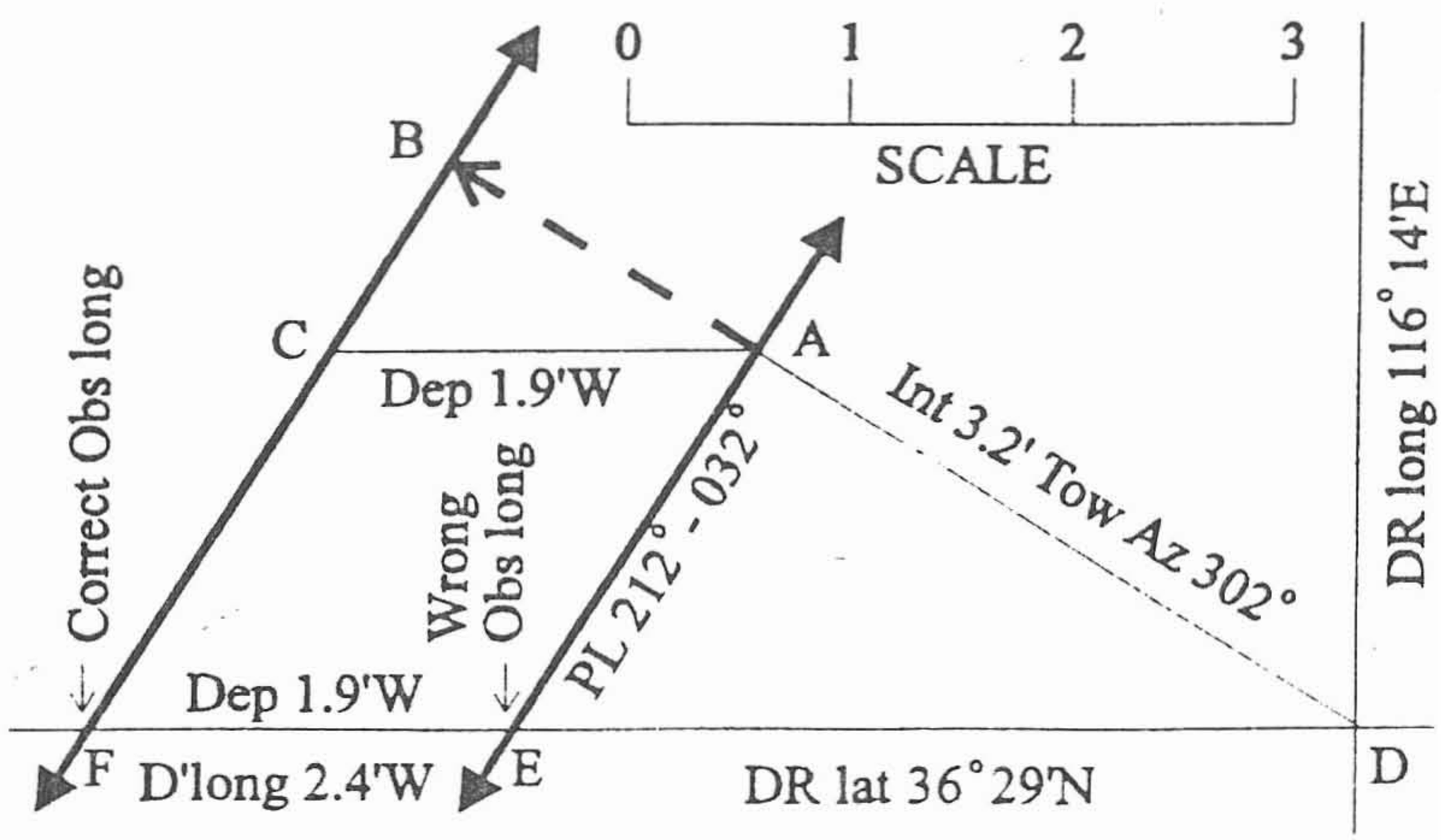
Using DR 36° 29'N 116° 24'E, an intercept of 3.7' Towards from Az 302°(T) was obtained. It was then discovered that the increment used for 58m 12s was taken from the almanac for the Sun instead of Aries. Find where the PL should be correctly drawn.

Increment that should have been used (Aries)	= 14° 35.4'
Increment that was used from almanac (Sun)	= 14° 33.0'
Difference	= 00° 02.4'

The increment used should be increased by 2.4' of arc.

Since long is E, LHA - GHA = Obs long.
Increase of GHA, in this case, would decrease Obs long by 02.4'.

The position line already obtained has to be shifted W by a d'long of 2.4'. Using lat 36.5°, dep = 1.9'W. This means that the ITP already obtained has to be shifted 270°(T) by a distance of 1.9 M. This is sufficient for actual use at sea.



If, for any reason, it is desired to know the correct intercept:
In this case, AB = AC x Cos 32° = 1.9 x Cos 32° = 1.6' Towards

Intercept already obtained	= 3.2 Towards
Correction to apply	= 1.6 Towards
Correct intercept in this case	= 4.8 Towards.

If, for any reason, it is desired to know the correct Obs longitude:
In this case, DF = correct dep West from DR position = DE + EF
= (Incorrect Intercept x Sec 32°) + 1.9 = (3.8 + 1.9) = 5.7' W.
Correct d'long from the DR position = 5.7 x Sec lat = 7.1' W.
Correct Obs longitude = 116° 14.0' - 000° 07.1' = 116° 06.9'E.

-o0o-

Exercise 28

(Simple errors in sights)

1 Using DR 32° 16'N 108° 57'W, a celestial observation gave an intercept of 0.8' Away from Az 320°(T). It was subsequently discovered that IE of 3.2' OFF the arc had not been applied. Find the correct intercept. If the sight had been worked as a long by chron, state the correct Obs long.

2 Using DR 62° 19'S an Obs long of 149° 34.7'E and an Az of 208.7° (T) was obtained. It was found later on that the HE used for the calculation was taken as 46 m instead of 26 m. Find the correct Obs long.

3 An ex-meridian alt of the Sun gave Obs lat 52° 42.3'S DR long 127° 56'E Az 355.7°(T). It was then found that the LL (correction +13.4') had been used in the calculation instead of UL (correction -18.4'). Find the correct Obs lat.

4 Using DR lat 53° 17'N, an observation of the Sun gave an Obs long of 79° 23.9'E and an Az of 125°(T). It was later found that chron error of 0m 22s Fast had been applied as Slow (added instead of subtracted). Find the correct Obs long. Also find what intercept to apply to the DR lat and the incorrect Obs long of 79° 23.9'E.

5 Using DR 46° 55'S 133° 48'W, an intercept of 2.5' Away from Az 139°(T) was obtained. It was then discovered that the increment used for 44m 28s was taken from the almanac for the Sun instead of Aries. Find where the PL should be correctly drawn.

-o0o-

20

COMPUTATION OF ALTITUDES

20.1 Meridian Altitudes

The average student is so used to working from the sextant meridian altitude to the latitude that he tends to get disoriented in this type of problem. This difficulty is overcome by writing the steps from the sextant altitude down to the latitude in the usual manner and working from bottom upwards, as follows:-

Worked example 1

On 23rd Sept 1992, in DR 23° 40'N 161°56'E, compute the sextant meridian altitude of the Sun's LL if IE was 2.3' on the arc and HE was 10.5m.

			From Almanac
Sext Alt	66° 06.3'	LMT mer pass	23d 11h 52m 00s
IE (on)	(-) 02.3'	LIT (E)	(-) 10 47 44
Obs alt	66° 04.0'	GMT mer pass	23d 01h 04m 16s
Dip (10.5m)	(-) 05.7'	Dec	00° 06.1' S
App alt	65° 58.3'	d (1.0)	(+) 00.1'
Tot corrn LL	(+) 15.5'	Dec	00° 06.2' S
T alt	66° 13.8' S		
MZD	23° 46.2' N		
Dec	00° 06.2' S		
Latitude	23° 40.0' N	PL :- E - W	

Note 1: First work out the declination as usual, as shown above on the right hand side.

2: Insert the values of DR lat & dec in the bottom columns.

3: Insert name of True alt by comparing the values of DR lat and dec (name of true alt = azimuth at mer pass).

4: Insert the name of MZD (opposite to that of true alt).

5: Compute the value of MZD bearing in mind the original thumb rule when working a normal lat by mer alt - if MZD and dec are of same name, add and retain the name; if of contrary names, subtract the smaller one from the larger one & retain the name of the larger one.

6: Insert the values and signs of the various corrections working from bottom upwards.

7: After obtaining the value of sext alt, work downwards once, as usual, to ensure that there are no mistakes.

Worked example 2

On 25th Feb 1992, in DR 10° 13'N 103°16'E, compute the sextant meridian altitude of the Moon's UL if IE was 1.6' on the arc and HE was 12m.

Sext Alt	56° 14.7'	GMT mer pass	24d 22h 44m
IE (on)	(-) 01.6'	dec including d corrn	23°24.8'S
Obs alt	56° 13.1'		
Dip (12m)	(-) 06.1'		
App alt	56° 07.0'	Approx app alt	56° 07.5'
Main corrn	(+) 42.1'	Approx main corrn	(+) 41.6'
	56° 49.1'		56° 49.1'
HP (55.8)	(+) 03.1'		
	56° 52.2'		
UL corrn	(-) 30.0'		
T alt	56° 22.2'S		
MZD	33° 37.8'N		
Dec	23° 24.8'S		
Latitude	10° 13.0'N	PL :- E - W	

Note 1: Work out the GMT of meridian passage to the nearest minute as explained in Chapter 17.2.

2: Then obtain the dec, applying d correction as usual.

3: Write down the steps and insert the signs of corrections.

4: Work upwards as described in worked example 1.

5: While working upwards, after applying HP correction, we get 56° 49.1'. Enter the alt corrn table with this value and obtain the approx value of main correction (41.6' in this case) and thence the approx app alt (56° 07.5' in this case). Enter the corrn table again with this app alt (56° 07.5'), obtain the main correction (42.1' in this case) and then continue the calculation upwards.

6: After obtaining the value of sext alt, work downwards once, as usual, to ensure that there are no mistakes.

20.2 Polaris

On 1st Sept 92, AM at ship in DR 17° 54'N 178° 11'E, compute the sextant altitude of the Pole star at 05h 21m 08s by chronometer (error 01m 18s slow). HE 12.5m, IE 1.6' on the arc.

GMT Aug 31d 17h 22m 26s (obtained as usual).

Sext alt	18°	47.2'
IE (on)	(-)	01.6'
Obs alt	18°	45.6'
Dip (12.5m)	(-)	06.2'
App alt	18°	39.4'
Tot Corrn	(-)	02.8'
T alt	18°	36.6'
a0	00°	16.5'
a1	00°	00.6'
a2	00°	00.3'
Sum	18°	54.0'
	(-) 1°	
Obs lat	17°	54.0'N

GHA γ	235°	07.3'
Incr	005°	37.4'
GHA γ	240°	44.7'
Long E	178°	11.0'
LHA γ	058°	55.7'

20.3 Others - (easily solved by the intercept method)

On 23rd Aug 92 PM in DR 34°31'S 003°30'W, compute the sextant altitude of SPICA when the chron (error 02m 19s slow) showed 06h 15m 00s. HE = 11m and IE = 2.1' on the arc.

GMT 23d 18h 17m 19s, obtained as usual.

Calculation of CZD by Nautical Tables:

Hav CZD = (Hav LHA . Cos L . Cos D) + Hav (L ~ D)

GHA γ	242° 16.6'	Log Hav LHA	9.10698
Incr	004° 20.5'	Log Cos L	9.91591
GHA γ	246° 37.1'	Log Cos D	9.99176
Long W	003° 30.0'	Log Hav sum	9.01465
LHA γ	243° 07.1'		
SHA ★	158° 47.8'		
LHA ★	041° 54.9'	Nat Hav Sum	0.10343
dec	11° 07.4'S	Nat Hav(L ~ D)	0.04110
lat	34° 31.0'S	Nat Hav CZD	0.14453
(L ~ D)	23° 23.6'	CZD	44° 41.3'

Calculation of CZD by scientific calculator

Cos CZD = Cos P . Cos lat . Cos dec ± Sin lat . Sin dec
= Cos 41° 54.9' . Cos 34° 31.0' . Cos 11° 07.4'
(+) Sin 34° 31.0' . Sin 11° 07.4' = 0.7109397
CZD = 44° 41.3'

Sext alt	45°	27.6'
IE (on)	(-)	02.1'
Obs alt	45°	25.5'
Dip (11m)	(-)	05.8'
App alt	45°	19.7'
Tot Corrn	(-)	01.0'
T alt	45°	18.7'
CZD	44°	41.3'

EXERCISE 29

(Altitude computation)

(1) On 21st Jan 1992, in DR 24° 38'S 110° 20'W, compute the sext mer alt of the Sun's LL. IE 1.6' off the arc. HE 10m.

(2) On 4th March 1992, DR 45° 14'N 120° 30'W, find the sext mer alt of ANTARES if IE = 3.2' off the arc and HE = 10m.

(3) On 5th May 92, in DR 50° 16'S 64° 15'W, find the sextant meridian altitude of SATURN if HE was 10m & IE was nil.

(4) On 21st July 1992, in DR 37° 25'N 96° 36'W, find the sext mer alt of the Moon's UL. IE = 0.4' off the arc. HE = 17m.

(5) On 1st Dec 1992, AM in DR 47° 15'N 143° 26'E, find the sextant altitude of Polaris at 08h 51m 15s chron time (error 05m 11s slow). IE was 2.1' off the arc and HE was 17m.

(6) On 22nd Sept 92, PM in DR lat 36° 28'N long 160° 12'W, compute the sextant altitude of Polaris at 05h 23m 17s chron time (error 02m 09s fast). IE = 2.8' on the arc, HE = 10m.

(7) On 30th April 1992, PM at ship in DR 34° 18'S 40° 20'W, find the sextant altitude of the star SIRIUS at 08h 52m 33s chron time (error 01m 10s fast), if HE = 21m and IE = nil.

(8) On 5th March 1992, AM at ship in DR 38° 11'S 151° 10'E, find the sext alt of the Sun's LL at 10h 54m 20s chron time (error 01m 20s slow). IE = 1.3' off the arc and HE = 30m.

(9) On 6th March 1992, AM in DR 00° 00' 60° 50'W, find the sextant altitude of the Moon's UL at 02h 44m 48s chron time (error 11m 16s fast). HE = 15m, IE = 0.4' off the arc.

(10) On 30th Nov 1992, PM at ship in DR 27° 45'S 140° 20'W, the compute the observed altitude of the Moon's UL at 11h 10m 08s chron time (error 00m 02s slow). HE was 10m.

21

STAR IDENTIFICATION

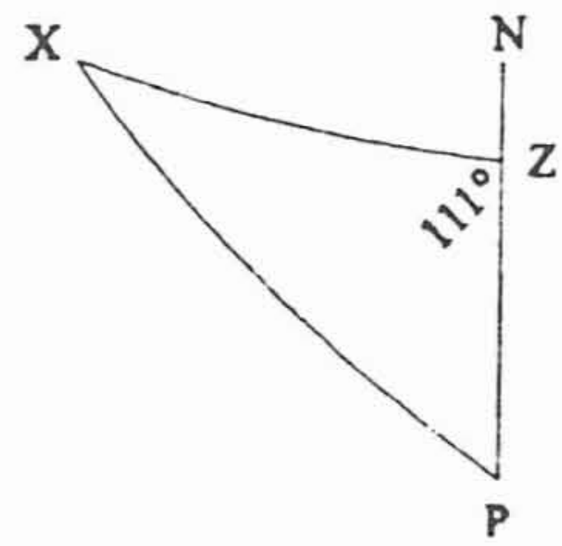
In cloudy weather, it may sometimes happen that a star sight is taken but the navigator is not able to identify the star with reference to the constellations because other stars are not visible for reference. In such a case, it is possible to identify the star by calculation. Thereafter, the position line can be obtained by the intercept, long by chron or ex-mer alt methods, as usual.

Using the DR position, the altitude and the time, the approximate values of declination and SHA can be calculated and the star identified by consulting pages of the Nautical Almanac. The daily pages of the almanac, normally used in calculations, lists the 57 stars of navigational importance in their alphabetical order. This is not convenient to use, in this case, as it would be a very tedious task to look for the calculated approximate values of SHA and declination when the listing is in alphabetical order.

On page 268 and onwards in the almanac, the stars are listed in ascending values of SHA. The left hand page gives the SHA and declination from January to June and the Latin reference names of the stars constellation-wise while the right hand page gives the SHA and declination from July to December and their English names. This is demonstrated by the following worked example:-

Worked example:

On 23rd Aug 1992 PM at ship in DR 34° 33'S 003° 30'W, in cloudy weather, the sextant altitude of an unknown star was found to be 45° 27.2' bearing 291°(T), when the chron (error 02m 19s slow) showed 06h 15m 00s. If HE was 11m and IE was 2.1' on the arc, identify the star.



GMT 23d 18h 17m 19s
(obtained as usual)

Sext alt	45°	27.2'
IE (on)	(-)	02.1'
Obs alt	45°	25.1'
Dip (11m)	(-)	05.8'
App alt	45°	19.3'
Tot Corrn	(-)	01.0'
T alt	45°	18.3'
TZD	44°	41.7'

GHA γ	242° 16.6'
Incr	004° 20.5'
GHA γ	246° 37.1'
Long W	003° 30.0
LHA γ	243° 07.1'

In spherical triangle PZX, shown in the figure above, Z = 111°, ZX = 44° 41.7, PZ = colat = 55° 27'. Required to find PX.

Calculation of dec by Nautical Tables:

Hav one side = Hav opp angle . Sin adj side . Sin adj side + Hav (diff between adj sides)

Hav PX = Hav Z . Sin PZ . Sin ZX + Hav (PZ ~ ZX)

= Hav 111°. Sin 55° 27'. Sin 44° 41.7' + Hav 10° 45.3'

Log Hav 111° 00.0'	9.83199	
Log Sin 55° 27.0'	9.91573	
Log Sin 44° 41.7'	9.84716	
Log Hav Sum	9.59488	

Nat Hav Sum	0.39344
Nat Hav 10° 45.3	0.00878
Nat Hav PX	0.40222
PX = Polar dist = 78° 43.4'	

Note: Since PX < 90°, the star is in the same hemisphere as the observer. Hence dec = (90° - PX). **Dec = 11° 16.6'S** (approx).

Calculation of dec by scientific calculator:

Cos one side = Cos opp angle . Sin adj side . sin adj side + Cos adj side . Cos adj side

Cos PX = Cos Z . Sin PZ . Sin ZX + Cos PZ . Cos ZX

Cos PX = Cos Z . Cos lat . Cos T alt + Sin lat . Sin T alt

= Cos 111°. Cos 34°33'. Cos 45°18.3'+Sin 34°33'. Sin 45°18.3'

= 0.1955492. PX = 78° 43.4'. **Dec = 11° 16.6'S** (approximate).

Calculation of LHA (long by chron fromula):

By Nautical Tables:

Hav LHA = Sec L . Sec D [Hav ZD - Hav (L ~ D)]

Nat Hav ZD	0.14457	Log Hav diff	9.01653
Nat Hav(L ~ D)	0.04069	Log Sec L	0.08427
Nat Hav diff	0.10388	Log Sec D	0.00847
LHA ★	**42° 01.9'**	Log Hav LHA	9.10927

Azimuth is 291°(T) so it is after mer pass. LHA has to be < 180

Calculation of LHA by scientific calculator:

$$\text{Cos P} = \frac{\text{Sin T alt} \mp \text{Sin lat . Sin dec}}{\text{Cos lat . Cos dec}}$$

Note:- If Lat and dec are same name (-), contrary names (+). Hence in the formula, (-) has been put above the (+). Entire numerator is Sin and entire denominator is Cos.

T alt = 45° 18.3' lat = 34° 33.0'S dec = 11° 16.6'S

$$\text{Cos P} = \frac{\text{Sin 45° 18.3'(-)Sin 34° 33.0'. Sin 11° 16.6'}}{\text{Cos 34° 33.0' . Cos 11° 16.6'}} = 0.742774$$

P = 42° 01.9'. Azimuth = 291°(T) so LHA has to be < 180°.

Hence in this case, P = **LHA★ = 042° 01.9'.**

To find SHA ★ from LHA ★

LHA ★ = LHA γ + SHA ★ or SHA ★ = LHA ★ - LHA γ

SHA ★ = 042° 01.9' - 243° 07.1' = 402° 01.9' - 243° 07.1'

SHA ★ = 158° 54.8' (approximate in this case).

By inspection of the Nautical Almanac, page 268 onwards in ascending values of SHA, it is seen that the star is SPICA (α Virginis), serial no: 33, stellar magnitude 1.2. Since the DR position was used to calculate the declination and the SHA, the computed values would differ by a small amount from those seen in the almanac. The sight can now be worked by the intercept or by the long by chron method to obtain the position line on which the ship lies.

If by chance the SHA and dec computed as above do not reasonably match those of any star, there is a possibility that it was a planet and not a star - it may not have been possible to distinguish this owing to a sudden sighting in between clouds. The *approximate* SHA and dec of each of the four planets used for navigation are listed in the daily pages of the almanac.

-o0o-

Exercise 30

(Star identification)

(1) On 22nd Sept 1992, PM at ship in DR 60° 10'N 92° 27'E, the sextant altitude of an unidentified star bearing 266°(T) was found to be 25° 01' at 00h 46m 31s by chron (error 05m 01s slow). If IE was 0.2' on the arc and HE was 17m, identify the star.

(2) On 31st Aug 1992, AM at ship in DR 40° 30'N 64° 56'E, the sextant altitude of a star bearing 220°(T) was 21° 23.4' when the chron (error 01m 06s fast) showed 00h 21m 32s. If IE was 0.9' off the arc and HE was 9m, identify the star.

(3) On 29th Nov 1992, AM at ship in DR 25° 30'S 107° 20'W, the sextant altitude of an unidentified star bearing 278° (T) was 35° 10.3' when the chron (error 02m 50s fast) showed 11h 32m 10s. If IE was 2.8' on the arc and HE was 12m, identify the star.

(4) On 19th Jan 1992, at about 1900 at ship in DR 00° 02'N 170° 50'E, the sextant altitude of an unidentified star bearing 080°(T) was observed to be 43° 11.1' when the chron (error 01m 18s fast) showed 07h 35m 02s. If HE was 18m and IE was 1.3' off the arc, identify the star.

(5) On 30th April 1992, PM at ship in DR 34° 18'S 40° 20'W, the sextant altitude of an unknown star bearing 295°(T) was 57° 48.6' at 08h 52m 05s chron time (error 00m 42s). If IE was 2.1' off the arc and HE was 21m, identify the star.

22

GREAT CIRCLE SAILING

A great circle track is the shortest distance, measured along the earth's surface, between the two places. A great circle track cuts successive meridians at different angles because the meridians are not parallel to one another. The course, therefore, should change slightly whilst crossing each meridian. Practically at sea, the departure and arrival positions are plotted on a Gnomonic chart and joined by a straight line. The vertex and suitable points are read off the chart and the navigator does Mercator sailing from point to point thereby following the Great Circle track effectively and conveniently.

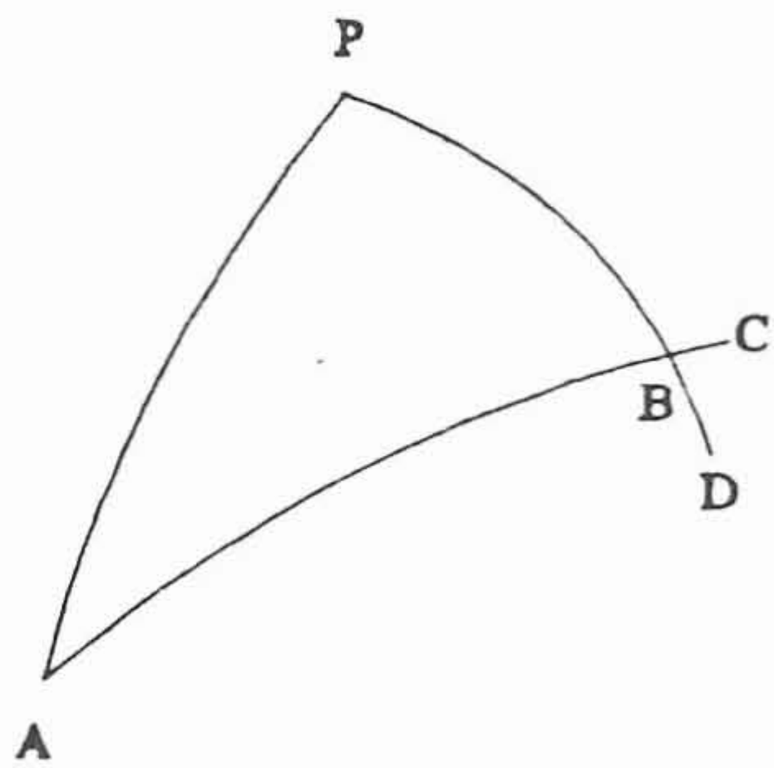
Before attempting to study this chapter, it is expected that the student would have a good understanding of spherical trigonometry as contained in Nutshell Series Book no: 8 - 'Spherical Trigonometry'. As far as possible, a navigational approach to the solution of each problem, rather than a purely mathematical one, has been maintained here. Values and *names* of A, B, C and Azimuth may be obtained from Nautical Tables or by using

formulae with the help of a scientific calculator as illustrated in earlier chapters.

By ABC Tables it is possible to directly calculate the initial and final courses. By the Hav formula, it is necessary to first calculate the GC distance and then only, the courses.

Worked example 1

Find the initial & final courses and the distance by a great circle track from A: 24°00'N 74°15'W to B: 46°00'N 53° 45'W.



	latitude	longitude
From A	24°00'N	074°15'W
To B	46°00'N	053°45'W
difference	22°00'N	020°30'E
A to B	d'lat	d'long

Notes:

(1) In a spherical triangle, the value of an angle must be less than 180° (see Nutshell Series Book 8 - Spherical Trigonometry - and also under d'long in Chapter 4.3 of this book).

(2) Since B lies to the East of A, all great circle courses from A to B must be *Easterly* (i.e., North Easterly or South Easterly) and not Westerly.

(3) The Initial and final courses can be calculated by the Haversine formula or by ABC tables.

(4) Although d'lat is N and d'long is E, the courses may be either NE'ly or SE'ly. This is described later under 'Vertex'.

Calculation of distance

Hav one side = Hav opp angle . Sin adj side . Sin adj side + Hav(diff bet adj sides).

So Hav AB = Hav P . Sin PA . Sin PB + Hav (PA ~ PB)

It is simpler to imagine that A is the observer and B is a celestial body:- lat of B = dec of body; d'long = angle P. Just substituting Z for A and X for B, the intercept formula can be applied as follows:-

Distance by Nautical Tables

Hav ZX = Hav P . Cos L . Cos D + Hav (L ~ D) or

Hav AB = Hav P . Cos lat A . Cos lat B + Hav (lat A ~ lat B)

Hav AB = Hav 20°30' . Cos 24°00' . Cos 46°00' + Hav 22°00'

AB = 27°30.1' = 1650.1'

Great Circle distance AB = 1650.1 Miles **Answer (i).**

Distance by Scientific calculator

Cos ZD = Cos P . Cos lat . Cos dec ± Sin lat . Sin dec

Note:- If Lat and dec are same name (+), contrary names (-). Hence in the formula, the (+) has been put above the (-).

If LHA lies between 0° and 180°, P = LHA

If LHA is between 180° & 360°, P = 360 - LHA

P = 20° 30.0' lat A = 24° 00.0'N lat B = dec = 46° 00.0'N

Cos ZD = Cos 20°30'.Cos 24°0'.Cos 46°0'+ Sin 24°0'.Sin 46°0'

Cos ZD = 0.8869959 ZD = 27° 30.1' = 1650.1'

Great Circle distance AB = 1650.1 Miles **Answer (i).**

Calculation of Initial course

This can be done by the Hav formula using Nautical Tables, since all the three sides are now known, or by ABC tables using Nautical Tables or a scientific calculator. Calculation through *ABC tables by a scientific calculator is fastest.*

Initial Course by Hav formula:

Hav one angle = Cosec adj side . Cosec adj side .
[Hav opp side - Hav diff bet adj sides)

Hav A = Cosec 66° . Cosec 27° 30.1' [Hav 44° - Hav 38° 29.9']

A = 31° 47.5' Initial course = N31° 47.5'E **Answer (ii).**

Initial course by ABC Tables:

P = 20° 30' (LHA 339° 30') lat A = 24°N lat B = dec = 46°N

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 24° 00.0'}}{\text{Tan 20° 30.0'}} = 1.1908182 \text{ S}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 46° 00.0'}}{\text{Sin 20° 30.0'}} = 2.9569060 \text{ N}$$

$$C = 1.7660878 \text{ N}$$

$$\text{Tan Az} = \frac{1}{\text{C (Cos 24° 00')}} = 0.6198085 \qquad \text{Az} = \text{N 31.791° E}$$

i.e., 031°47.5' (T)

Initial course = N31° 47.5'E **Answer (ii).**

Note: By ABC Tables it is possible to directly calculate the initial and final courses. By the Hav formula, it is necessary to first calculate the GC distance and then only, the courses.

Calculation of final course

The angle of the spherical triangle, calculated by any means, would be inside the triangle: angle PBA in this case. This is the angle between True North and the ship's stern (refer to the figure at the beginning of this example). So the final course PBC would, in this case, be PBA ± 180° as the ship's heading is BC.

Final Course by Hav formula:

Hav one angle = Cosec adj side . Cosec adj side .
[Hav opp side - Hav diff bet adj sides)

Hav PBA = Cosec 44°.Cosec 27° 30.1'[Hav 66° - Hav 16° 29.9']

PBA = 136° 08.8'. Final course = 043° 51.2'(T) **Answer (iii).**

Final course by ABC Tables:

P = 20° 30' (LHA 339° 30') lat B = 46°N lat A = dec = 24°N

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 46° 00.0'}}{\text{Tan 20° 30.0'}} = 2.7696516 \text{ S}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 24° 00.0'}}{\text{Sin 20° 30.0'}} = 1.2713287 \text{ N}$$

$$C = 1.4983229 \text{ S}$$

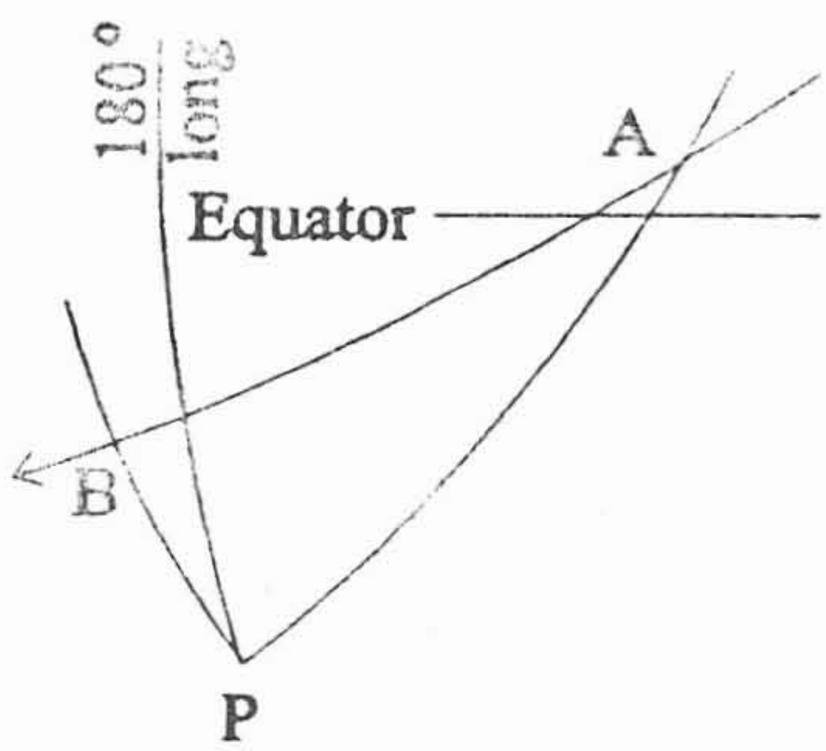
$$\text{Tan Az} = \frac{1}{\text{C (Cos 46° 00')}} = 0.9607785$$

Az = S 43.854° W
i.e., 223°51.2' (T)

Final course = 043° 51.2'(T) **Answer (iii).**

Worked example 2

Find the great circle distance, initial course and final course from A 06°00'N 79°00'W to B 38°00'S 179°00'E.



	latitude	longitude
From A	06°00'N	079°00'W
To B	38°00'S	179°00'E
difference	44°00'S	102°00'W
A to B	d'lat	d'long

Notes:

(1) Since the higher latitude is in the Southern Hemisphere, P represents the South Pole.

(2) Since B lies to the West of A, the great circle courses from A to B must be *Westerly* (i.e North Westerly or South Westerly) and not Easterly.

(3) Although d'lat is S and d'long is W, the courses may be either SW'ly or NW'ly as described later under 'Vertex'.

Calculation of distance

Hav one side = Hav opp angle . Sin adj side . Sin adj side + Hav(diff bet adj sides).

So Hav AB = Hav P . Sin PA . Sin PB + Hav (PA ~ PB)

As explained in worked example 1, imagine that A is the observer and B is a celestial body:- lat of B = dec of body; d'long = angle P. Just substituting Z for A and X for B, the intercept formula can be applied as follows:-

Distance by Nautical Tables

Hav ZX = Hav P . Cos L . Cos D + Hav (L ~ D) or

Hav AB = Hav P . Cos lat A . Cos lat B + Hav (lat A ~ lat B)

Hav AB = Hav 102°00' . Cos 06°00' . Cos 38°00' + Hav 44°00'

AB = 103° 08.3' = 6188.3'

Great Circle distance AB = 6188.3 Miles **Answer (i).**

Distance by Scientific calculator

Cos ZD = Cos P . Cos lat . Cos dec ± Sin lat . Sin dec

Note:- If Lat and dec are same name (+), contrary names (-). Hence in the formula, the (+) has been put above the (-).

If LHA lies between 0° and 180°, P = LHA

If LHA is between 180° & 360°, P = 360 - LHA

P = 102° (P = LHA); lat A = 06° 0.0'N; lat B = dec = 38° 0.0'S

Cos ZD = Cos 102° . Cos 06° . Cos 38° - Sin 06° . Sin 38°

Cos ZD = - 0.2272932 ZD = 103° 08.3' = 6188.3'

Great Circle distance AB = 6188.3 Miles **Answer (i).**

Initial course by Hav formula

Hav one angle = Cosec adj side . Cosec adj side . [Hav opp side - Hav diff bet adj sides)

Initial course by ABC Tables:

P = 102° (LHA = P) lat A = 06°N lat B = dec = 38°S

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 06° 00.0'}}{\text{Tan 102° 0.0'}} = 0.0223405 \text{ N}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 38° 00.0'}}{\text{Sin 102° 0.0'}} = 0.7987400 \text{ S}$$

$$C = 0.7763994 \text{ S}$$

$$\text{Tan Az} = \frac{1}{\text{C (Cos 06° 00')}} = 1.2950915$$

Az = S 52.327° W
i.e., 232°19.6' (T)

Initial course = 232° 19.6'W **Answer (ii).**

Final Course by Hav formula:

Hav one angle = Cosec adj side . Cosec adj side .
[Hav opp side - Hav diff bet adj sides)

Hav B = Cosec 52°.Cosec 103° 08.3' [Hav 96° - Hav 51° 08.3']

Internal ∠ B = S87°21.3'E. Vertically opposite ∠ = N87°21.3'W

Final course = N87° 21.3'W = 272° 38.7'(T) **Answer (iii).**

Final course by ABC Tables:

P = 102° (LHA = P); lat B = 38° 0.0'S; lat A = dec = 06° 0.0'N

$$A = \frac{\text{Tan lat}}{\text{Tan P}} = \frac{\text{Tan 38° 00.0'}}{\text{Tan 102° 0.0'}} = 0.1660673 \text{ S}$$

$$B = \frac{\text{Tan dec}}{\text{Sin P}} = \frac{\text{Tan 06° 00.0'}}{\text{Sin 102° 0.0'}} = 0.1074523 \text{ N}$$

$$C = 0.0586150 \text{ S}$$

$$\text{Tan Az} = \frac{1}{\text{C (Cos 38° 00')}} = 21.650037$$

Az = S 87.355° E
i.e., S 87°21.3'E

Final course = N 87°21.3'W = 272° 38.7'(T) **Answer (iii).**

VERTEX

The vertex of a great circle is that point where the great circle reaches its maximum latitude.

Each great circle has two vertices, one in each hemisphere and they are 180° apart.

The d'long between the point where a great circle crosses the equator and the vertex of that great circle is 90°.

After crossing the equator the latitude keeps on increasing and the course constantly changes, cutting each meridian at a different angle.

As the great circle track goes further and further away from the equator, it will be observed that the N-S component of the course gets less and less whereas the E-W component increases. This continues until the vertex is reached.

At the vertex, the N-S component is zero while the E-W component is maximum. The course of the vessel at the vertex is therefore either exactly East or exactly West (i.e., 090° or 270°). Nowhere else can the great circle course be exactly E or W.

After crossing the vertex, the N-S component gradually increases and the E-W component decreases until the great circle crosses the equator again, at the same angle as it did before.

The knowledge of the position of the vertex is useful to the navigator for two reasons:-

(i) If the latitude of the vertex is too high the navigator may want to modify the course as he would like to avoid the ice, fog, extreme cold and bad weather which are associated with very high latitudes.

(ii) The knowledge of the position of the vertex helps in quickly calculating the position of any intermediate position on the great circle track.

Practically at sea, the starting position and the destination are marked on a Gnomonic chart and joined by a straight line. This straight line represents a great circle track on that chart. The position of the vertex is read off directly from the Gnomonic chart as mentioned in the first page of this chapter. Intermediate points on the track are also read off from the chart and rhumb line courses and distances between them calculated. Such a method is very quick and practical but is not as accurate as the calculations shown here.

Before proceeding to calculate the position of the vertex, it is essential to know whether the vertex lies to the East of the starting point A, or to the West of it. This is easily known by very elementary reasoning as described below:-

If both A and B are in the same hemisphere, the vertex to consider also lies in the same hemisphere.

If A and B are in different hemispheres, the vertex to consider is the one in the same hemisphere as the higher of the two latitudes.

If the initial and final courses are in different quadrants, the vertex lies between A and B (i.e. if initial course is NE and the final course is SE; if initial course is NW and the final course is SW; etc.).

If the initial & final courses are in the same quadrant, the vertex lies outside AB (i.e. on AB produced or on BA produced).

Bearing the above facts in mind, let us examine the following illustrations where the initial and final courses are given and we have to reason out whether the vertex lies to the East of A or to the West of A.

A. Where we consider the North Pole & hence the Northern Vertex:-

This happens either when both A & B are in the Northern Hemisphere OR when they are in different hemispheres but the higher of the two latitudes is in the Northern Hemisphere.

1.
Initial Co N70°E Final Course S80°E
Therefore V lies between A & B i.e. to the East of A but West of B.

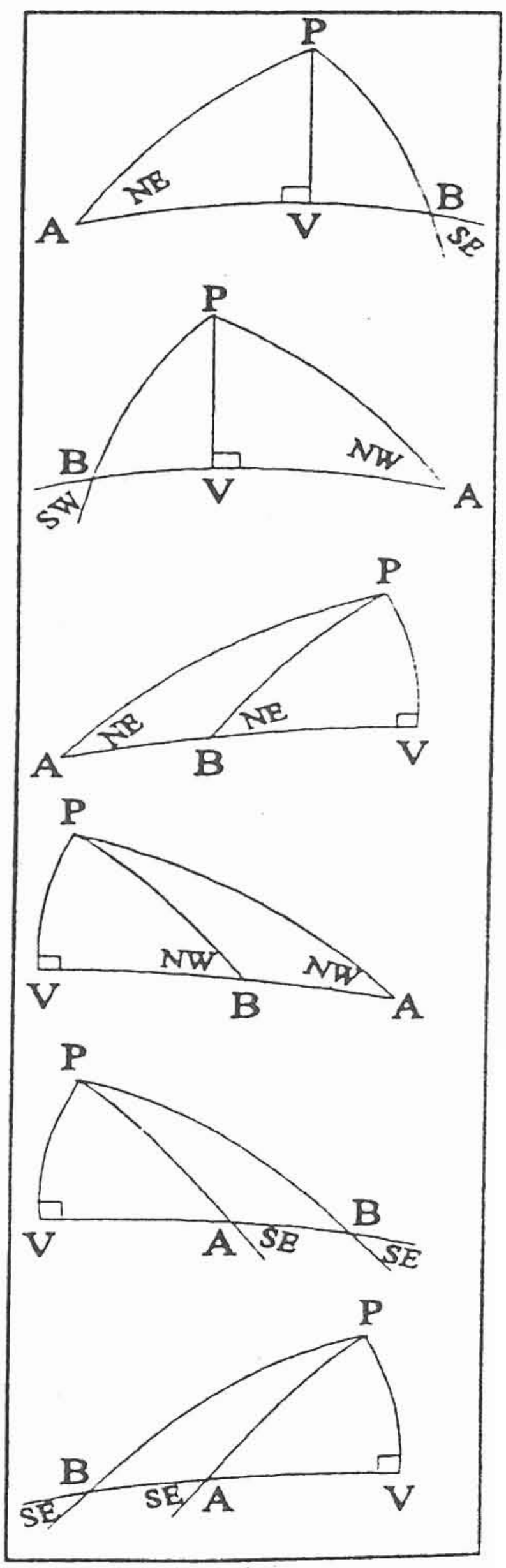
2.
Initial Co N65°W Final Course S85°W
Therefore V lies between A & B i.e. to the West of A but East of B.

3.
Initial Co N45°E Final Course N70°E
Therefore V lies on AB produced i.e. to the East of A and B.

4.
Initial Co N50°W Final Course N80°W
Therefore V lies on AB produced i.e. to the West of A and B.

5.
Initial Co S60°E Final Course S50°E
Therefore V lies on BA produced i.e. to the West of A and B.

6.
Initial Co S70°W Final Course S40°W
Therefore V lies on BA produced i.e. to the East of A and B.



B. Where we consider the South Pole & hence the Southern Vertex:-

This happens either when both A & B are in the Southern Hemisphere OR when they are in different hemispheres but the higher of the two latitudes is in the Southern Hemisphere.

1.
Initial Co S70°E Final Course N80°E
Therefore V lies between A & B i.e. to the East of A but West of B.

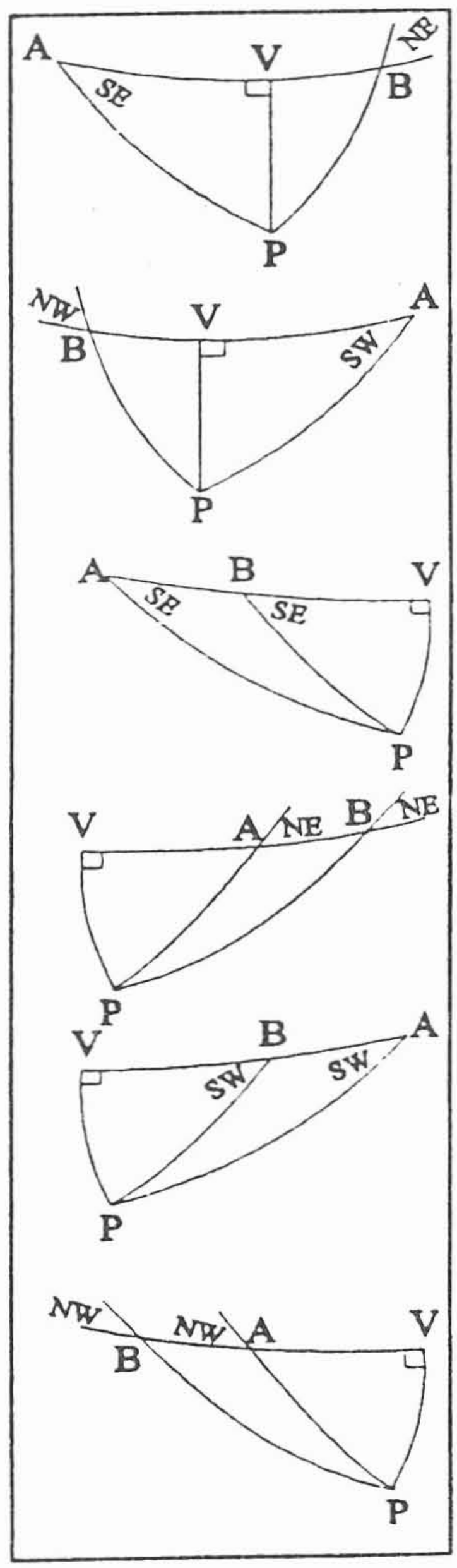
2.
Initial Co S60°W Final Course N75°W
Therefore V lies between A & B i.e. to the West of A but East of B.

3.
Initial Co S50°E Final Course S65°E
Therefore V lies on AB produced i.e. to the East of A and B.

4.
Initial Co N70°E Final Course N60°E
Therefore V lies on BA produced i.e. to the West of A and B.

5.
Initial Co S40°W Final Course S70°W
Therefore V lies on AB produced i.e. to the West of A and B.

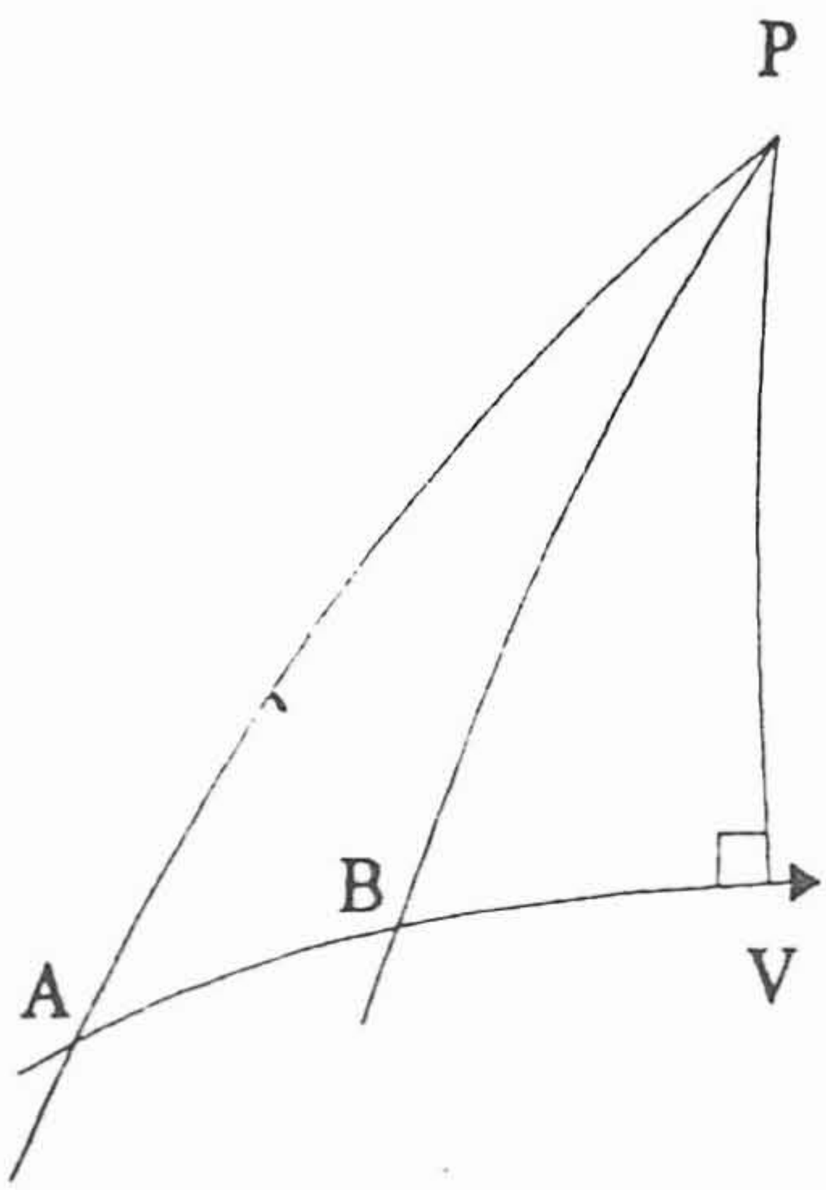
6.
Initial Co N80°W Final Course N50°W
Therefore V lies on BA produced i.e. to the East of A and B.



Worked example 3

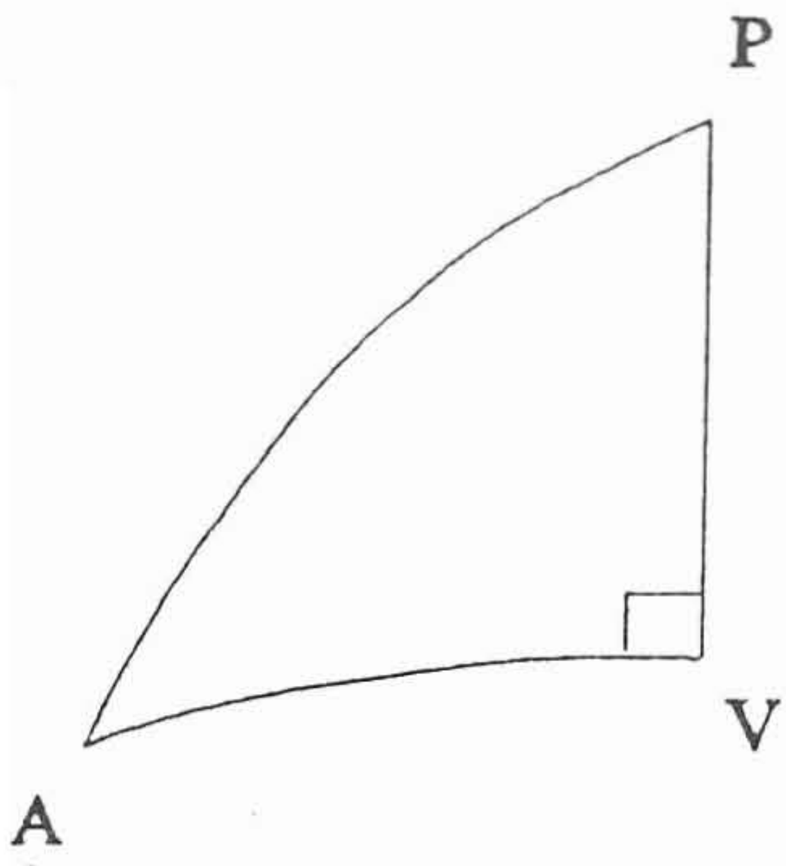
On a great circle passage from A: 24° 00'N 74° 15'W to B: 46° 00'N 53° 45'W, calculate the position of the vertex.

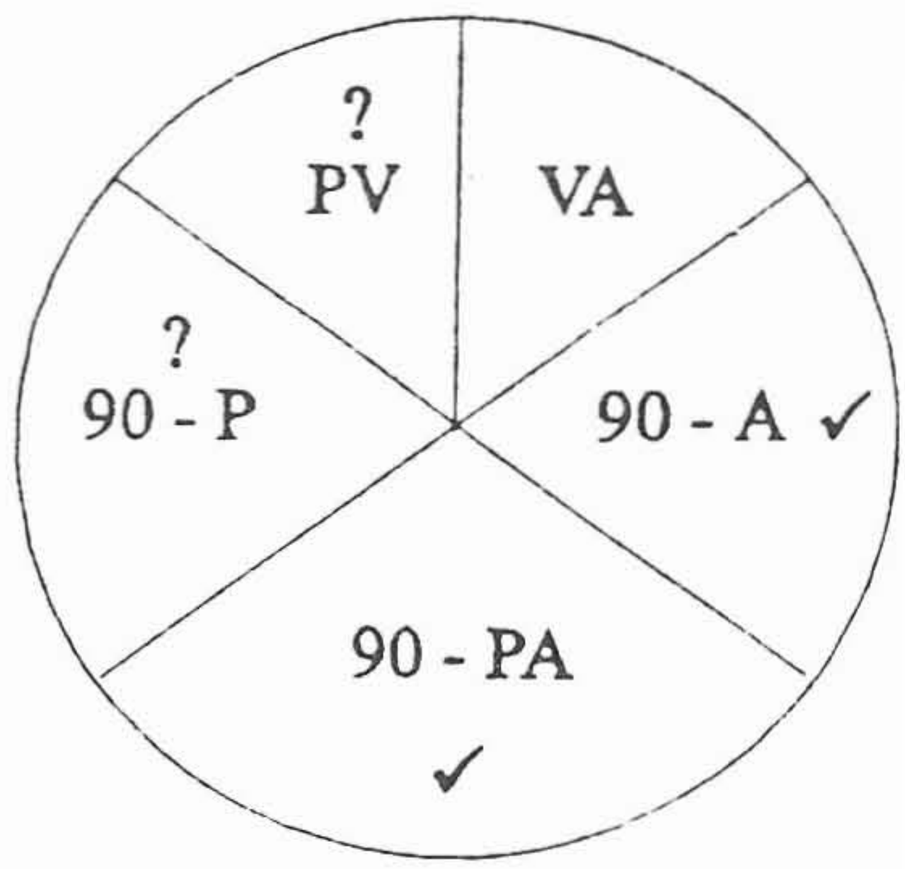
First calculate the initial and final courses, as illustrated earlier, preferably by ABC Tables. Since the positions are the same as those in worked example 1, the working is not shown here. Initial course = N31° 47.5'E & final course = N43° 51.2'E.



We are going from N lat to more N lat. Both, initial and final courses, are in the same quadrant i.e., both NE. Hence the vertex lies on AB produced i.e., East of B.

Given below is Napier's diagram and some formulae for the calculation of the position of the vertex. The use of Napier's Rules is described in detail in Nutshell Series Book 8 - Spherical Trigonometry. In practical navigation, students may, if they desire, learn the two formulae by heart and apply them directly.





In spherical triangle PVA, ∠ V is a right angle because PV is the meridian of V and the course at point V is exactly E or W (East in this case).

Formula for latitude of V	Formula for d'long of V
Sin mid part = Cos opp . Cos opp	Sin mid part = Tan adj . Tan adj
Sin PV = Cos (90-A) . Cos (90-PA)	Sin (90-PA) = tan (90-A) . tan (90-P)
Cos lat V = Sin A . Cos lat A	**Tan P = Cot A . Sec PA**
also	also
Cos lat V = Sin B . Cos lat B	**Tan P = Cot B . Sec PB**

Note: ∠ P = d'long which can sometimes be > 90°. So the sign of Tan P is very important. If Tan P is (+), ∠ P is less than 90°. If Tan P is (-), ∠ P will, in navigation, be between 90° and 180°. So it is important to leave Sec PA or Sec PB as it is in the above formulae and not convert it to Cosec lat A or Cosec lat B. This is clearly illustrated in worked example 5.

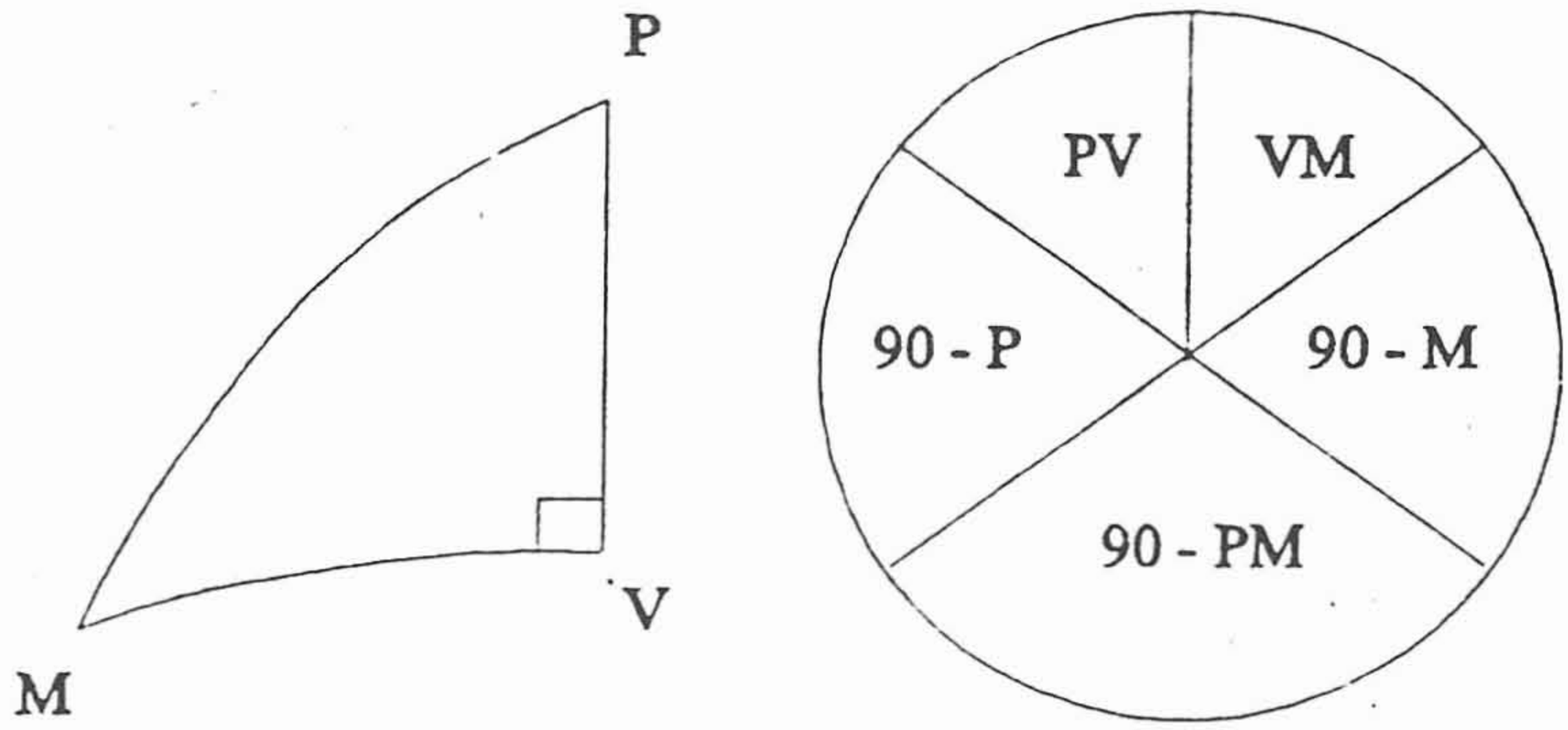
Latitude of V	Longitude of V
Cos lat V = Sin A . Cos lat A	Tan P = Cot A . Sec PA
= Sin 31° 47.5' . Cos 24°	= Cot 31° 47.5'. Sec 66°
↓	d'long from A = 75° 51.0'E
	long of A = 74° 15.0'W
lat V = 61° 13.8'N	long of V = 01° 36.0'E

INTERMEDIATE POINTS ON THE GC TRACK

Having found the latitude and longitude of the vertex, the calculation of any intermediate points on the great circle track is very simple. If the latitude of a point on the track is chosen, its longitude can be calculated and vice versa.

Worked example 4

In worked example 3, find where the GC track crosses: (a) the meridian of 65°W and (b) the 36°N parallel of latitude.



(a) PV = 28° 46.2', P = d'long V to M = 66° 36.0', PM = ?

Sin mid = Tan adj .Tan adj <u>or</u> Sin (90-P) = Tan PV.Tan (90-PM)

Cos P = Tan PV . Cot PM or **Tan PM = Tan PV . Sec P**

Tan PM = Tan 28° 46.2' . Sec 66° 36.0'. PM = 54° 07.3'

Lat where GC crosses 65°W = 35° 52.7'N **Answer (a).**

(b) In the foregoing Napier's diagram, substitute N for M.

PV = 28° 46.2', PN = colat N = 54°, P = d'long V to N = ?

Sin mid = Tan adj .Tan adj <u>or</u> Sin (90-P) = Tan PV.Tan (90-PN)

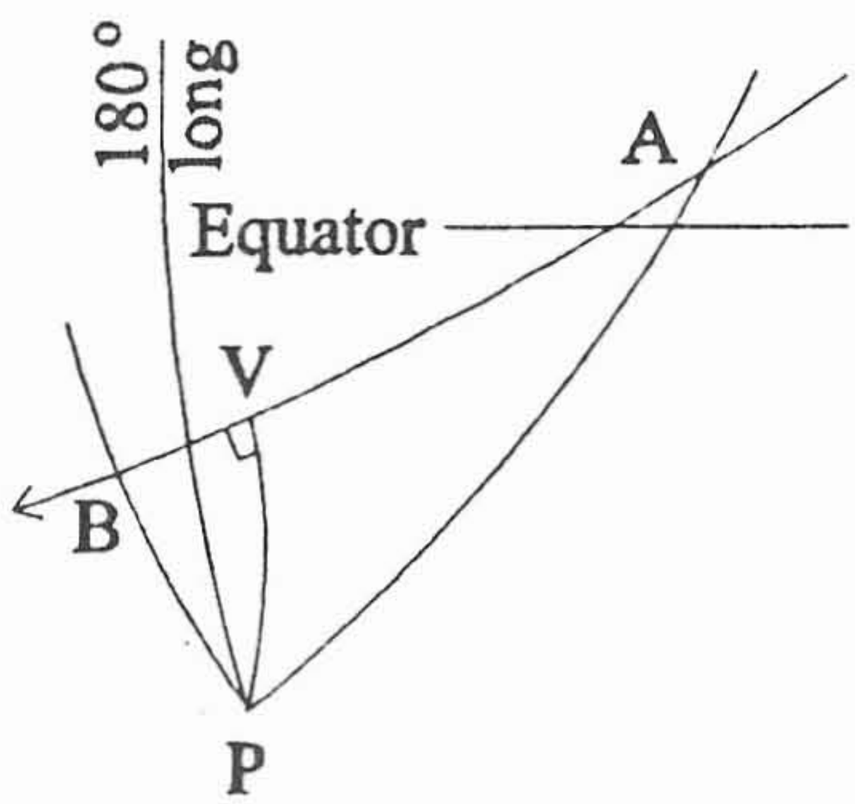
Cos P = Tan PV . Cot PN = Tan 28° 46.2' . Cot 54°

P = 66° 29.3' = d'long W from meridian of Vertex (i.e. 01° 36'E)

Longitude where GC crosses 36N is 64° 53.3'W **Answer (b).**

Worked example 5

Find the position of the vertex of the great circle track in worked example 2 (from A: 06°N 079°W to B: 38°S 179°E). Also find where the track crosses (a) 85°W and (b) 02°N.



Already calculated earlier:

Initial Course S52° 19.6'W

Final Course N87° 21.3'W

In Δ PAV, A = 52° 19.6'

lat A = 06° 00'N, V = 90°

Using the same Napiers diagram & formulae as in worked example 3:

<u>Latitude of V</u>

Cos lat V = Sin A . Cos lat A
= Sin 52° 19.6' . Cos 06°
= 0.7871721

↓

lat V = 38° 04.7'S **answer**

<u>Longitude of V</u>

Tan P = Cot A . Sec PA
= Cot 52° 19.6'. Sec 96°
= - 7.386932

d'long from A = 97° 42.6'W*
long of A = <u>79° 00.0'W</u>
long of V = 176° 42.6'W

* Since the sign of Tan P is negative, ∠ P > 90°. This is why Sec PA was retained instead of converting it to Cosec lat.

INTERMEDIATE POINTS ON THE GC TRACK

Using the Napiers diagram and formulae in worked example 4:

(a) PV = 51° 54.3', P = d'long V to M = 91° 42.6', PM = ?

Tan PM = Tan 51° 55.3' . Sec 91° 42.6'. PM = 91° 20.3'

Lat where GC crosses 85°W = 01° 20.3'N **Answer (a).**

(b) In the same Napier's diagram, substituting N for M:

PV = 51° 55.3', PN = colat N = 92°, P = d'long V to N = ?

Cos P = Tan PV . Cot PN = Tan 51° 55.3' . Cot 92°

P = 92° 33.3' = d'long E from of Vertex (i.e. 176° 42.6'W)

Longitude where GC crosses 02°N is 84° 09.3'W **Answer (b).**

Exercise 31

(Great Circle Sailing)

In the following cases, find the initial course, final course, distance and the position of the vertex along the great circle track:

	FROM		TO	
	Latitude	Longitude	Latitude	Longitude
1	30° 20.0'S	142° 45.0'W	50° 40.0'S	170° 30.0'E
2	69° 30.0'N	060° 50.0'E	44° 40.0'N	120° 20.0'E
3	10° 00.0'S	150° 00.0'W	40° 00.0'N	160° 00.0'E
4	49° 50.0'N	005° 15.0'W	32° 29.0'N	064° 00.0'W
5	39° 00.0'S	020° 00.0'W	40° 00.0'S	142° 00.0'E
6	19° 00.0'N	067° 00.0'W	36° 00.0'N	006° 00.0'W

7 Find the latitude in which the great circle track in question 1 crosses the meridian of 180°.

8 Find the longitude in which the great circle track in question 3 crosses the equator.

9 Find the longitude in which the great circle track in question 4 crosses the parallel of 40° N.

10 Find the latitude in which the great circle track in question 6 crosses the meridian of 40° W.

23

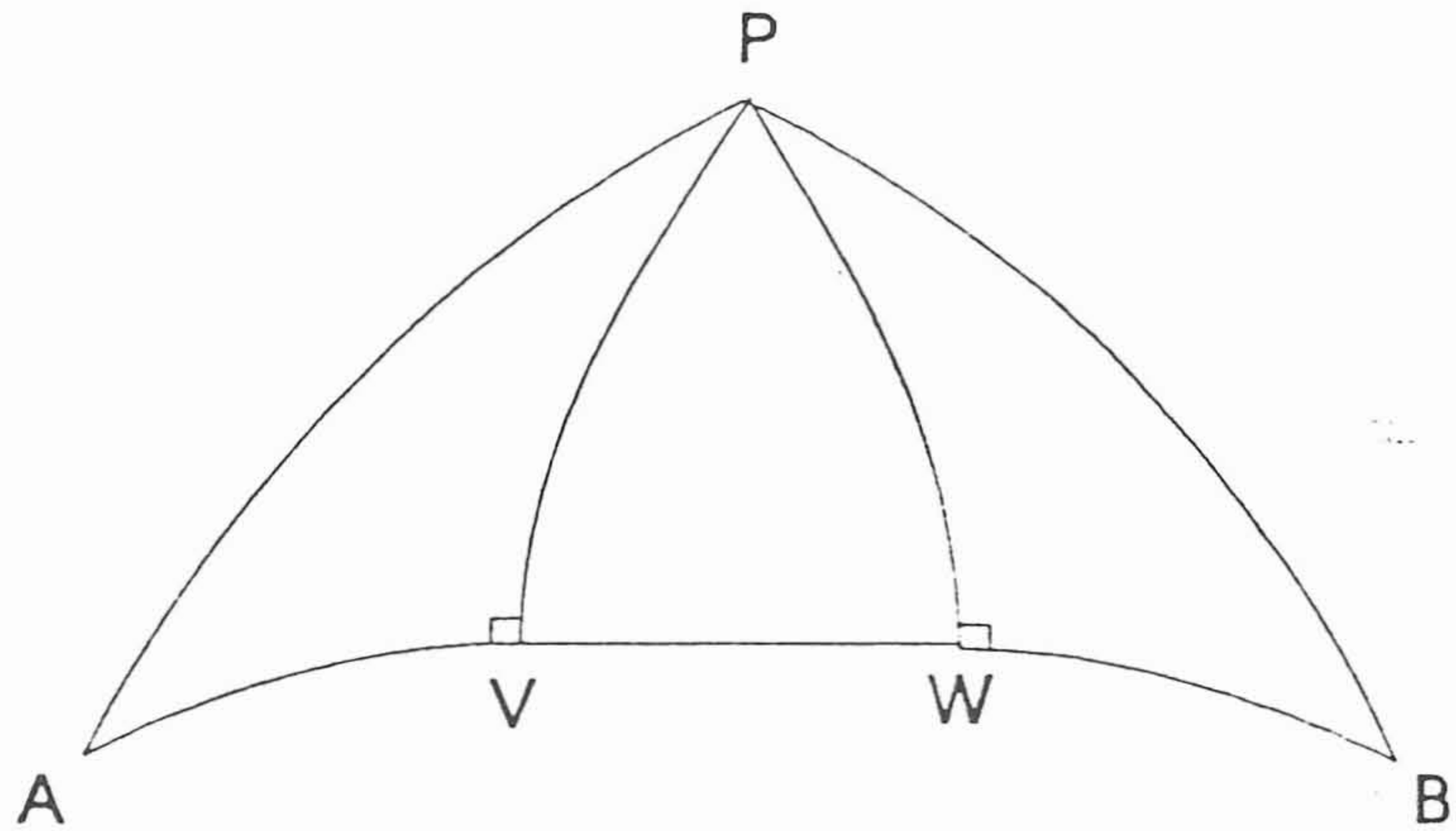
COMPOSITE CIRCLE SAILING

In some cases, the great circle track from one place to another may pass through very high latitude which the navigator would like to avoid because of frontal depressions, severe cold, fog, ice bergs, etc associated with very high latitudes. In such cases, the navigator decides on the maximum latitude of the passage and does a modified form of great circle sailing called Composite Circle Sailing.

From starting position A, a great circle track is drawn such that its vertex V is the ceiling latitude. Similarly, a great circle track is drawn backwards from destination B such that its vertex W is also the ceiling latitude (i.e., latitude V = latitude W).

The navigator then sails along the great circle track AV and, on reaching V (ceiling latitude), he sails along the parallel of latitude. On reaching W, he sails along the great circle track WB. The great circle tracks AV and WB are arcs of two *separate* great circles. The leg VW is the arc of a parallel of latitude and is hence *not* a great circle track. AVWB is hence called a composite track.

The derivation of the formulae, by Napier's Rules, for calculating the various aspects - longitude of each of the vertices V and W (of the two great circle tracks), the distance along each great circle tracks, initial and final courses, etc - are very simple but some students may prefer to memorise them and apply them directly.



Worked example 1

Find the initial course, final course and the distance along the composite track from A: 51° 20'N 010° 00'E to B: 52° 00'N 55° 00'E, having a ceiling latitude of 53°N.

Using the Napier's diagram and formulae used in chapter 22, under the heading 'vertex', the calculation is very simple.

In spherical Δ PAV, V = 90°	In spherical Δ PBW, W = 90°
PA = 38° 40', PV = 37° 00',	PB = 38° 00', PW = 37° 00',
Sin A = Cos lat V . Sec lat A	Sin B = Cos lat W . Sec lat B
Sin A = Cos 53° . Sec 51° 20'	Sin B = Cos 53° . Sec 52° 00'
Initial course = N74° 24.9'E	**Final course** = S77° 49.5'E
Cos AV = Sin lat A÷Sin lat V	Cos WB = Sin lat B÷Sin latW
AV = 12° 08.0' = 728.0 **Miles**	WB = 9° 21.4' = 561.4 **Miles**

Cos P = Tan lat A÷Tan lat V	Cos P = Tan lat B÷Tan lat W
d'long A to V = 19° 39.5'E	d'long B to W = 15° 18.7'W
long of A = 10° 00.0'E	long of B = 55° 00.0'E
long of V = 29° 39.5'E	**long of W** = 39° 41.3'E

d'long VW = 10° 01.8' = 601.8'

Dist VW = Dep = d'long . Cos lat = 601.8 . Cos 53° = 362.2 M

Total dist = AV + VW + WB = 728 + 362.2 + 561.4 = **1651.6M**

Worked example 2

In worked example 1, calculate the longitude where the composite track first crosses 52°N.

Using the Napier's diagrams and formulae in chapter 22:
Cos P = Tan lat M ÷ Tan lat V = Tan 52° ÷ Tan 53° = 0.964505

d'long from V = 15° 18.7'W
Long of V = 29° 39.5'E
Long of M = 14° 20.8'E **Answer**

Worked example 3

In worked example 1, find the latitude where the composite track crosses 45°E.

Using the Napier's diagrams and formulae in chapter 22:
d'long W to N = 05° 19'E Tan lat N = Cos P . Tan lat W
Tan lat N = Cos 05° 19' . Tan 53° **Answer** lat N = 52° 52.9'N

-o0o-

Exercise 32

(Composite Circle Sailing)

In the following cases, find the initial course, final course, distance along the composite circle track:

	FROM		TO		Max
	Latitude	Longitude	Latitude	Longitude	Lat
1	45° 54.0'S	170° 45.0'E	49° 06.0'S	075° 50.0'W	55°S
2	39° 00.0'S	020° 00.0'E	40° 00.0'S	142° 00.0'W	50°S
3	37° 48.0'N	122° 40.0'W	35° 40.0'N	141° 00.0'E	45°N

4 In example 1 above, calculate the longitude in which the track crosses the latitude of 50°S for the first time (i.e from N to S)

5 In example 3 above, calculate the latitude in which the track crosses the meridian of 180°.

-o0o-

24

ALTITUDE

ABOVE AND

BELOW POLE

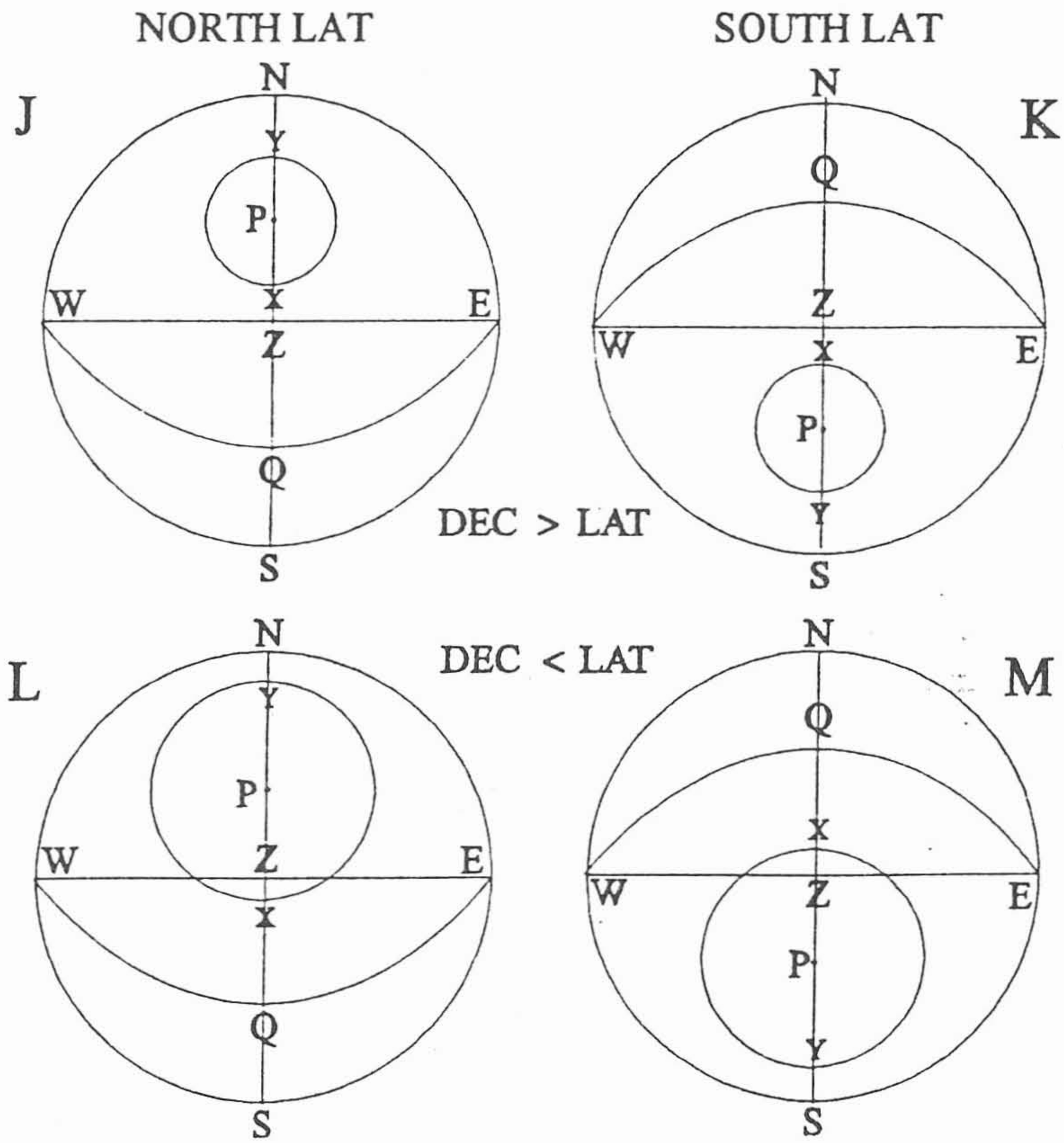
The meridian 180° away from the observer's longitude is called the observer's inferior meridian. The passage of a celestial body across the observer's inferior meridian is called the lower meridian passage or meridian passage below the pole. The normal meridian passage is then referred to as the upper meridian passage or meridian passage above the pole. The time interval between the upper and lower meridian passages of the Sun is 12 hours and that of a star, is 11h 58m 02s (half a sidereal day). During upper meridian passage, LHA = 0° or 360° and during lower meridian passage, LHA = 180°.

Under certain conditions (of latitude and declination), a celestial body may remain above the rational horizon - does not set - and is then theoretically visible at all times, even during lower meridian passage. Under such conditions, the body is said to be circumpolar. In reality, it is possible that during one or both of these meridian passages, a circumpolar star or planet may not be practically visible due to the presence of strong sunlight.

To understand the calculations involving altitudes above and below the pole, it is necessary to first understand the figure drawn on the plane of the observer's rational horizon. This is described in detail in Chapter 3.

The angle P, measured westerly from X_R (the position of the body when it is rising) and X_S (the position of the body when it is setting), expressed in hours and minutes and seconds, is the duration of time that the body would be above the observer's rational horizon. We notice from figures F and I in Chapter 3 that, as declination increases, the body remains above the rational horizon for a longer period, and vice versa.

If the latitude and declination are sufficiently high, the body would remain above the rational horizon as shown below:



In addition to the description given for the figures in Chapter 3, the foregoing figures J, K, L and M require the following further explanation.

At upper mer pass	**At lower mer pass**
ZX - zenith distance	ZY - zenith distance
PX - polar distance	PY - polar distance
<u>In figures J & M</u>	<u>In figures J & L</u>
NX - true altitude	NY - true altitude
<u>In figures K & L</u>	<u>In figures K & M</u>
SX - true altitude	SY - true altitude

It will be seen that for a body to be circumpolar:

(i) Lat and dec must be of same name (i.e., both N or both S).

(ii) NP ≥ PY or lat ≥ polar dist or lat ≥ 90 - dec
or latitude + declination ≥ 90°

<u>Deductions based on figures J, K, L and M</u>

(i) NX ~ NY = XY also SX ~ SY = XY
If dec is constant, PX = PY or XY = 2 . PX

(ii) In N lat, NP = PY + NY and in S lat, SP = PY + SY
Lat = polar dist + lower mer alt

Worked example 1

The true altitude of a star at upper meridian passage and lower meridian passage were 63° 54' and 16° 50' respectively, to an observer in the northern hemisphere. At both transits, the star bore North. Find his latitude and the declination of the star.

<u>Refer to figure J of this chapter.</u>

Mer alt above pole	= NX =	63° 54'N
Mer alt below pole	= NY =	<u>16° 50'N</u>
2 (Polar distance)	= XY =	47° 04'
Polar distance	= PX =	23° 32'
Declination = 90° - PX	=	66° 28'N
Mer alt below pole	= NY =	16° 50'
Polar distance	= PY =	<u>23° 32'</u>
Latitude = NP	=	40° 22'N

Worked example 2

In North latitude, the meridian altitudes of a star were observed as follows:

Upper mer alt = 82° 36' bearing South
Lower mer alt = 15° 48' bearing North
Find latitude and declination.

Refer to figure L of this chapter.
Upper mer alt = SX = 82° 36'
NX = 180° - SX = 97° 24'
Lower mer alt = NY = 15° 48'
2 (polar dist) = XY = 81° 36'
Polar distance = PX = 40° 48'
Declination = 90-PX = 49° 12'N

Lower mer alt = NY = 15° 48'
Polar distance = PY = 40° 48'
Latitude = NP = 56° 36'N

Worked example 3

In the southern hemisphere, the meridian altitude of a star above and below the pole were 63° 12' and 17° 46' respectively, both times bearing South. Find the latitude and the declination.

Refer to figure K of this Chapter.
Upper mer alt = SX = 63° 12'
Lower mer alt = SY = 17° 46'
2 (polar dist) = XY = 45° 26'
Polar distance = PX = 22° 43'
Declination = 90 - PX = 67° 17'
Lower mer alt = SY = 17° 46'
Polar distance = PY = 22° 43'
Latitude = SP = 40° 29'S

Worked example 4

In South latitude, the sextant meridian altitudes of a star were observed as follows:

Upper mer alt = 79° 27.5' bearing N

Lower mer alt = 14° 08.5' bearing S

If HE was 11m and IE was 2.3' off the arc, find the declination and the latitude.

Refer to figure M of this chapter.

	Upper	Lower
Sext Alt	79° 27.5'	14° 08.5'
IE (off)	(+) 02.3'	(+) 02.3'
Obs alt	79° 29.8'	14° 10.8'
Dip (11m)	(-) 05.8'	(-) 05.8'
App alt	79° 24.0'	14° 05.0'
Tot corrn	(-) 00.2'	(-) 03.8'
T alt	79° 23.8'	14° 01.2'

Upper mer alt = NX = 79° 28.8'

SX = 180 - NX = 100° 36.2'

Lower mer alt = SY = 14° 01.2'

2 (polar dist) = XY = 86° 35.0'

Polar distance = PY = 43° 17.5'

Dec = 90 - PY = 46° 42.5'S

Lower mer alt = SY = 14° 01.2'

Polar distance = PY = 43° 17.5'

Latitude = SP = 57° 18.7'S

Worked example 5

Given latitude as 32° 11'N and declination as 69° 36'N, compute the meridian altitudes above and below the pole.

Draw figure NESW and insert WQE, NZS and P. Since dec > lat, the body will bear N during upper mer pass. The figure is hence the same as figure J of this Chapter.

Lat = NP	= 32° 11'	NY = 2 (PY)	= 40° 48'
Polar dist = PY	= 20° 24'	Lower mer alt = NY =	11° 47'
Lower mer alt = NY =	11° 47'	Upper mer alt = NX =	52° 35'

Worked example 6

If latitude was 64° 27'S and declination was 39° 47'S, compute the upper and lower meridian altitudes.

Draw figure NESW and insert WQE, NZS and P. Since dec < lat, the body will bear N during upper mer pass. Hence refer to figure M.

Lat = SP	= 64° 27'	XY = 2 (polar dist)	= 100° 26'
Polar dist = PY	= 50° 13'	Lower mer alt = SY =	14° 14'
Lower mer alt = SY =	14° 14'	SX	= 114° 40'
		NX = (180 - SX)	= 65° 20'

Worked example 7

In North latitude, the lower meridian altitude of a star of declination 37° 50'N and 10° 41' by sextant. If IE was 2.1' off the arc, and HE was 10m, find the latitude and compute the sextant altitude for the upper meridian passage.

Sext Alt	10° 41.0'	Dec = 37° 50'N
IE (off)	(+) 02.1'	PY = 52° 10'
Obs alt	10° 43.1'	
Dip (10m)	(-) 05.6'	
App alt	10° 37.5'	
Tot corm	(-) 05.0'	
T alt	10° 32.5'	

Draw figure NESW and insert WQE, NZS and P. Since dec < lat, the body will bear S during upper mer pass. Hence refer to figure L.

XY = 2 (polar dist)	= 104° 20.0'	
NY	= 10° 32.5'	
NX	= 114° 52.5'	
SX = 180 - NX	= 65° 07.5'S	= Upper mer alt

Sext Alt	65° 11.5'
IE (off)	(+) 02.1'
Obs alt	65° 13.6'
Dip (10m)	(-) 05.6'
App alt	65° 08.0'
Tot corm	(-) 00.5'
T alt	65° 07.5'

Sext alt at upper mer pass = 65° 11.5'

Worked example 8

On 16th June 1992, in DR long 156° 08'E in high North latitude, the sextant meridian altitude of the Sun's LL below pole was 10° 14.8'. HE 11m, IE 1.6' on the arc. Find the latitude.

Figure L is applicable.

Sext Alt	10° 14.8'	LMT upper mer pass	16d 12h 01m 00s
IE (on)	(-) 01.6'	Difference	. 12 .
Obs alt	10° 13.2'	LMT lower mer pass	16 00 01 00
Dip (11m)	(-) 05.8'	LIT (E)	(-) 10 24 32
App alt	10° 07.4'	GMT lower mer pass	15d 13h 36m 28s
Tot corn LL	(+) 10.8'	Declination	23° 20.0' N
T alt	10° 18.2'	d correction (0.1)	(+) 00.1'
Polar dist	66° 39.9'	Declination	23° 20.1' N
Latitude	76° 58.1'N		

From Almanac

Worked example 9

On 25th Feb 1992, in South latitude, DR long 120° 42'E, the sextant meridian altitude of the Moon's UL below pole was 05° 07.2'. If HE was 13m and IE was 0.2' on the arc, find the latitude and the direction of the PL.

Sext Alt	05° 07.2'	Appr LMT lower mer pass	25d 18h 18m
IE (on)	(-) 00.2'	Long E, Earlier	24 17 26
Obs alt	05° 07.0'	Daily difference	. 52
Dip (13m)	(-) 06.3'	Long corrn = 120.7(52)/360 =	- 17
App alt	05° 00.7'	Appr LMT lower mer pass	25d 18h 18m
Main corrn	(+) 58.2'	Corr LMT lower mer pass	25 18 01
HP (55.5)	(+) 02.0'	LIT (E)	(-) 08 03
	06° 00.9'	Corr GMT lower mer pass	25 09 58
UL corrn	(-) 30.0'	declination	24° 02.6'S
T alt	05° 30.9'	d (+3.0)	(+) 00.5'
Polar dist	65° 56.9'	declination	24° 03.1'S
Latitude	71° 27.8'N	PL :- E - W	

Worked example 10

If the upper meridian altitude of a star was three times its lower meridian altitude, find the declination and the latitude in terms of the lower meridian altitude.

Refer to figure J or K

Let lower mer alt = x. Then upper mer alt = 3x

2 (polar dist) = alt above pole - alt below pole = 3x - x = 2x

∴ Polar dist = x and declination = (90 - x) **answer (i).**

Latitude = alt below pole + polar dist = x + x = 2x **answer (ii).**

Both lat and dec are of same name - both N or both S.

-o0o-

25

STARS SUITABLE FOR OBSERVATION

The idea here is to find out, at the time of civil twilight on a given day in the ship's DR position, what stars would be available for observation by a sextant. The SHA of an imaginary star which would be on the observer's meridian at that time is computed. Then a ± value of hour angle (say 45° or 60° or some such value) is decided by the observer and the applied to the SHA of the imaginary star. The limits of SHA are now available for consulting the almanac.

As explained in the first page of Chapter 21, the almanac (pages 268 onwards) lists the stars in ascending order of SHA, along with their English names, Latin names and stellar magnitudes. Extracting the names of the suitable stars, whose SHA falls within the chosen limits, is a simple procedure as illustrated in the following worked examples.

Stars having a stellar magnitude of 1.0 or lower are referred to as first magnitude and those between 1.0 and 2.0 are called second magnitude stars.

Worked example 1

On the evening of 1st December 1992, in DR 44° 27'N 93° 50'E, what stars of the first or second magnitude, or planets, will be within 45° of hour angle from the observer's meridian?

GHA γ	220° 30.8'	LMT civil twilight	01d	16h	53m	00s
Incr	9° 26.5'	LIT (E)	(-)	06	15	20
GHA γ	229° 57.3'	GMT	01	10	37	40
Long E	093° 50.0'	LHA γ + SHA ★ = LHA ★				
LHA γ	323° 47.3'	At mer pass ★, LHA ★ = 360°				

∴ SHA ★ = 360° - LHA γ = 360° - 323° 47.3' = 036° 12.7'

An imaginary star of SHA 036° 12.7' would be on the observer's meridian at the above time. So the required stars are those whose SHA is 351° 12.7' to 081° 12.7' (036° 12.7' ± 45°).

Consulting the pages at the back of the almanac, as explained in Chapter 21, first and second magnitude stars, within these limits of SHA, may be extracted.

On the daily pages of the almanac, the approximate SHA of each planet, for that day, is given. By inspection of these, planets having SHA within the desired limits can be extracted.

From the almanac (page 268 onwards), the stars are: Fomalhaut - magnitude 1.3, Deneb - magnitude 1.3, Altair - magnitude 0.9 and Vega - magnitude 0.1. Planets Venus and Saturn also fall within the desired limits of SHA.

Worked example 2

On 1st May 92, PM in DR 48° 20'N 27° 40'W which 1st or 2nd magnitude stars are suitable for ex-meridian observation?

GHA γ	175° 02.2'	LMT civil twilight	01d	19h	49m	00s
Incr	9° 56.6'	LIT (W)	(+)	01	50	40
GHA γ	184° 58.8'	GMT	01	21	39	40
Long W	027° 40.0'	LHA γ + SHA ★ = LHA ★				
LHA γ	157° 18.8'	At mer pass ★, LHA ★ = 360°				

∴ SHA ★ = 360° - LHA γ = 360° - 157° 18.8' = 202° 41.2'

SHA of an imaginary star on the observer's meridian at that time is 202° 41.2'. From the almanac (page 268 onwards), the following stars have a near value of SHA:

Name of Star	Regulus	Dubhe	Miaplacidus
Magnitude	1.3	1.0	1.8
SHA ★	208° 00.2'	194° 10.5'	221° 43.3
LHA γ	157° 18.8'	157° 18.8'	157° 18.8'
LHA ★	005° 19.0'	351° 29.3'	019° 02.1'
∠ P	005° 19.0	008° 30.7'	019° 02.1'
time from mer pass	21 minutes	34 minutes	76 minutes
Declination	12° 00.2'N	61° 47.7'N	69° 41.6'S
DR latitude	48° 20.0'N	48° 20.0'N	48° 20.0'N
Ex-mer limit	36 minutes	31 minutes	not possible

Star Regulus: It is only 21 minutes after mer pass with an Ex-mer limit of 36 minutes. Hence it is suitable.

Star Dubhe: It is 34 minutes *before* mer pass with an Ex-mer limit of 31 minutes. Hence it is suitable if the sight is taken five or six minutes later.

Planet Venus: By similar calculation as above, Ex-mer limit is about 38 minutes. Venus is suitable for *lat by mer alt* and also Ex-meridian observation.

-o0o-

Exercise 33

(Stars suitable for observation)

1 On 6th March 1992 in DR 20° 12'N 75° 30'E, find which first magnitude stars will be within 30° of hour angle from the observer's meridian at the end of PM civil twilight.

2 On 13th Sept 1992, in DR 34° 40'S 126° 39'W, find which 1st and 2nd magnitude stars will be within 45° of hour angle from the observer's meridian at the end of PM civil twilight.

3 On 17th Jan 1992, in DR 46° 17'N 174° 30'E, find the planets and 1st magnitude stars that will be within 40° of hour angle from the observer's meridian at the beginning of AM civil twilight.

4 On 30th Nov 1992, in DR 33° 10'N 100° 30'W, find whether any 1st or 2nd magnitude stars will be suitable for an Ex-mer observation at the beginning of morning civil twilight.

5 On 23rd Sept 1992, in DR 36° 48'S 144° 00'E, during PM civil twilight, find what 1st or 2nd magnitude stars will be within 30° of hour angle from the observer's meridian. State also which of these are suitable for an Ex-mer observation.

-o0o-

ANSWERS

Exercises 1 & 2 - Plane sailing & traverse tables (pages 30 & 39)

1	05° 48.1'N	062° 28.0'E	9	N43° 32'E	- 340.5M
2	11° 31.5'S	127° 50.3'W	10	S20° 38'W	- 322.0M
3	07° 49.2'N	177° 25.2'E	11	N47° 20'W	- 024.1M
4	58° 24.3'N	110° 43.4'E	12	S31° 22'E	- 051.4M
5	25° 18.6'S	162° 23.7'W	13	S59° 57'W	- 103.6M
6	S22° 52'E	- 273.5M	14	N31° 45'E	- 022.3M
7	S48° 04'W	- 512.6M	15	S38° 43'W	- 033.2M
8	N11° 03'E	- 368.1M			

Exercise 3 - Mercator sailing (page 47)

1	N37° 08'E	- 1655.7M	6	21° 28.3'N	117° 32.0'W
2	S65° 19'W	- 6321.7M	7	59° 55.0'N	141° 54.1'E
3	N67° 27'W	- 4333.9M	8	68° 38.8'S	074° 48.8'E
4	S27° 57'E	- 1188.6M	9	64° 53.5'N	086° 02.3'W
5	S68° 28'W	- 2836.1M	10	08° 36.9'N	048° 22.0'W

Exercise 4 - Accumulated rate of chronometer (page 74)

1 GMT 07d 17h 56m 37s
2 GMT 19d 02h 21m 06s
3 GMT 04d 13h 23m 57s

Exercise 5 - Mer alt Sun (page 86)

	GMT	d	h	m	s	MZD	Obs lat	PL
1	Jan	21	19	32	20	04° 42.4'	24° 38.4'S	E-W
2	Sept	01	08	38	12	08° 15.3'	00° 07.1'S	E-W
3	April	30	23	57	08	25° 15.4'	40° 20.7'N	E-W
4	Sept	14	19	40	48	19° 49.3'	16° 44.3'S	E-W
5	Dec	01	16	06	12	28° 19.4'	06° 24.8'N	E-W

Exercise 6 - Azimuth Sun (page 89)

GMT	h	m	s	LHA		T Az	Err	Dev
1 29	17	47	49	319°	22.4'	136.7°	6.7°E	3.7°E
2 22	10	09	38	059°	55.2'	259.8°	5.2°W	7.2°W
3 19	04	48	00	064°	54.0'	269.3°	2.3°E	Nil
4 30	11	00	52	285°	43.6'	074.5°	5.5°W	4.5°W
5 31	17	10	20	077°	33.1'	280.7°	1.3°W	4.3°W

Exercise 7 - Amplitude Sun (page 91)

GMT	h	m	s	T Az	Err	Dev
1 02	01	09	40	079.6°	10.4°W	5.4°W
2 02	06	36	00	287.9°	2.9°E	4.9°E
3 20	23	26	48	234.0°	Nil	3.0°E
4 30	00	15	10	124.4°	14.4°E	4.4°E
5 23	13	50	48	090.3°	3.7°W	1.0°W

Exercise 8 - Long by chron Sun (page 94)

1 GMT 31d 15 09 50 TZD 50° 40.0' GHA 047° 25.2' Cal LHA 047°21.0' Obs long 000°04.2W Az 289.8° PL 019.8 - 199.8°.
2 GMT 30d 13 00 52 TZD 46° 08.2' GHA 015° 55.7' Cal LHA 315°41.9' Obs long 060°13.8W Az 069.4° PL 159.4 - 339.4°.
3 GMT 19d 03 48 00 TZD 46° 27.2' GHA 234° 23.2' Cal LHA 049°40.0' Obs long 175°16.8'E Az 279.9 PL 009.9 - 189.9°.
4 GMT 22d 10 09 38 TZD 70° 14.6' GHA 334° 15.2' Cal LHA 059°37.1' Obs long 085° 21.9'E Az 246.4 PL 156.4 - 336.4°.
5 GMT 04d 22 55 40 TZD 53° 54.3' GHA 161° 01.3' Cal LHA 312°05.4' Obs long 151°04.1'E Az 066.0 PL 156.0 - 336.0°.

Exercise 9 - Intercept Sun (page 98)

1 GMT 04d 22h 55m 40s LHA 312°11.3' TZD 53°54.3' CZD 53° 50.0' Int 04.3' Away Az 065.9° PL 155.9° - 335.9° (T).
2 GMT 22d 10h 09m 38s LHA 059°55.2' TZD 70°14.6' CZD 70° 25.6' Int 11.0' Towards Az 246.7° PL 156.7° - 336.7 (T).

3 GMT 19d 03h 48m 00s LHA 049°54.2' TZD 46°27.2' CZD 46°37.9' Int 10.7' Towards Az 279.7° **PL** 009.7° - 189.7° (T).

4 GMT 30d 13h 00m 52s LHA 315°43.7' TZD 46°08.2' CZD 46° 06.5 Int 01.7' Away Az 069.4° PL 159.4° - 339.4° (T).

5 GMT 31d 15h 09m 50s LHA 047°25.2' TZD 50°40.0' CZD 50°43.8' Int 03.8' Towards Az 289.8° PL 019.8° - 199.8° (T).

Exercise 10 - Ex-mer alt Sun (page 102)

1 GMT 01d 00h 49m 12s LHA 357°19.5' TZD 15°19.1' MZD 15°06.1' Obs lat 23°21.5'N Az 169.9° PL 079.9 - 259.9° (T).

2 GMT 02d 17h 37m 48s LHA 005°02.5' TZD 31°27.4' MZD 31°03.6' Obs lat 15°27.2'S Az 350.7° PL 080.7° - 260.7° (T).

3 GMT 06d 01h 27m 30s LHA 009°42.6' TZD 58°31.2' MZD 57°55.9' Obs lat 52°18.4'N Az 191.4° PL 101.4 - 281.4° (T).

4 GMT 21d 18h 25m 32s LHA 355°46.4' TZD 20°19.6' MZD 19°54.0' Obs lat 00°02.6'S Az 168.5° PL 078.5 - 258.5° (T).

5 GMT 23d 01h 00m 12s LHA 355°43.0' TZD 48°19.1' MZD 48°10.5' Obs lat 48°16.6'S Az 005.7° PL 095.7° - 275.7° (T).

Exercise 11 - Mer alt Star (page 105)

	GMT	MZD	Obs lat	PL
1		71° 39.1'	45° 14.1N	E - W
2	Sept 12 00 21 08	59° 28.9'	42° 59.1'S	E - W
3	Sept 21 23 09 31	16° 42.9'	24° 55.3'S	E - W
4	Jan 21 03 41 26	75° 37.3'	57° 35.4'N	E - W
5	May 02 04 26 45	18° 07.8'	30° 08.0'N	E - W

Exercise 12 - Azimuth Star (page 107)

	GMT	h	m	s	LHA		T Az	Err	Dev
1	05	22	35	16	289°	04.0'	073.7°	4.3°W	1.3°W
2	01	07	39	22	092°	47.2'	299.5°	3.5°E	6.5°E
3	30	13	00	08	032°	30.9'	320.6°	8.6°E	1.4°W
4	14	04	36	00	068°	09.5'	270.1°	4.9°W	0.1°E
5	20	20	20	00	226°	29.3'	034.4°	0.1°W	4.1°W

Exercise 13 - Long by chron Star (page 111)

1 GMT 29d 11 29 20 TZD 55°00.0' GHA★ 162°22.7' Cal LHA 055°01.3' Obs long 107°21.4'W Az 278.1° PL 008.1 - 188.1°

2 GMT 22d 12 51 32 TZD 65°08.6' GHA★ 340°41.2 Cal LHA 073°19.7' Obs long 092°38.5'E Az 265.3° PL 355.3 - 175.3°

3 GMT 19d 07 33 44 TZD 46°56.1' GHA★ 142°42.1' Cal LHA 313°30.7' Obs long 170°48.6'E Az 079.9° PL 169.9 - 349.9°

4 GMT 30d 20 51 23 TZD 32°18.0' GHA★ 070°41.3' Cal LHA 030°17.0' Obs long 040°24.3'W Az 295.2° PL 025.2 - 205.2°

5 GMT 31d 00 20 26 TZD 68°43.5' GHA★ 333°43.8' Cal LHA 038°46.3' Obs long 065°02.5'E Az 219.6° PL 129.6° - 309.6°

Exercise 14 - Intercept Star (page 114)

1 GMT 30d 20h 51m 23s LHA★ 030°21.3' TZD 32°18.0' CZD 32°21.2' Int 03.2' Towards Az 295.2° PL 025.2° - 205.2° (T).

2 GMT 19d 07h 33m 44s LHA★ 313°32.1' TZD 46° 56.1' CZD 46°54.7' Int 01.4' Away Az 079.9° PL 169.9° - 349.9° (T).

3 GMT 29d 11h 29m 20s LHA★ 055°02.7' TZD 55°00.0' CZD 55°01.2' Int 01.2' Towards Az 278.1° PL 008.1° - 188.1° (T).

4 GMT 31d 00h 20m 26s LHA★ 038°39.8' TZD 68°43.5' CZD 68°39.4' Int 04.1' Away Az 219.6° PL 129.6° - 309.6° (T).

5 GMT 22d 12h 51m 32s LHA★ 073°08.2' TZD 65°08.6' CZD 65°02.9' Int 05.7' Away Az 265.3° PL 175.3° - 355.3° (T).

Exercise 15 - Ex-mer alt Star (page 117)

1 GMT 12d 15h 54m 26s LHA★ 001°17.8' TZD 16°57.3' MZD 16°54.4' Obs lat 00°24.6'S Az 355.7° PL 085.7° - 265.7° (T).

2 GMT 02d 10h 54m 20s LHA★ 010°38.5' TZD 72°51.0' MZD 72°11.8' Obs lat 44°09.1'S Az 350.2° PL 080.2° - 260.2° (T).

3 GMT 20d 02h 15m 52s LHA★ 003°39.2' TZD 25°06.1' MZD 24°54.9' Obs lat 44°08.0'N Az 188.2° PL 098.2° - 278.2° (T)

4 GMT 06d 00h 22m 26s LHA★ 354°04.5' TZD 59°32.5' MZD 59°24.1' Obs lat 66°48.4'N Az 173.2° PL 083.2° - 263.2° (T)

5 GMT 21d 01h 15m 10s LHA★ 002°25.1' TZD 67°00.8' MZD 66°58.6' Obs lat 20°59.2'S Az 358.2° PL 088.2° - 268.2° (T).

Exercise 16 - Polaris (page 120)

	GMT d h m s	LHAγ	Obs lat	Az	PL
1	Nov 30 20 56 26	167°31.1'	47°14.9N	359.1°	089.1-269.1°
2	Sept 23 05 21 08	282°23.8'	36°27.9N	000.9°	090.9-270.9°
3	Apr 30 17 30 30	271°32.0'	51°05.5N	000.9°	090.9-270.9°

	T Az	Error	Dev
3	000.9°	4.1°W	5.1°W
4	359.7°	3.7°E	7.4°E
5	001.0°	11.0°E	1.0°E

Exercise 17 - Mer alt Planet (page 123)

	GMT	d	h	m	s	MZD	Obs lat	PL
1	May	05	10	45	45	34° 06.0'	50° 16.6'S	E-W
2	Jan	17	00	53	20	52° 24.2'	45° 01.1'S	E-W
3	Oct	14	13	02	20	28° 49.7'	51° 58.6'N	E-W
4	Nov	30	08	25	44	73° 56.0'	56° 11.3'N	E-W
5	May	04	00	01	24	24° 00.1'	35° 00.0'N	E-W

Exercise 18 - Azimuth Planet (page 125)

	GMT	h	m	s	LHA	T Az	Err	Dev
1	23	05	19	00	048° 12.4'	279.8°	6.2°W	3.2°W
2	30	23	55	20	281° 35.8'	099.7°	3.7°E	7.4°E
3	17	23	10	00	266° 27.2'	118.7°	1.3°W	0.7°E

Exercise 19 - Long by chron Planet (page 128)

1 GMT 16d 23 39 38 TZD 70°22.2' GHA 211°30.5' Cal LHA 311°52.4' Obs long 100°21.9'E Az 132.5° PL 042.5 - 222.5°

2 GMT 01d 12 23 34 TZD 43°44.4' GHA 300°08.5' Cal LHA 046°16.3' Obs long 106°07.8'E Az 275.3° PL 005.3° - 185.3°

3 GMT 23d 04 11 00 TZD 35°13.2' GHA 108°17.0' Cal LHA 328°10.2' Obs long 140°06.8'W Az 060.4° PL 150.4 - 330.4°

4 GMT 29d 23 44 02 TZD 41°27.9' GHA 304°53.3' Cal LHA 045°09.3' Obs long 100°16.0'E Az 260.0° PL 170.0° - 350.0°

5 GMT 02d 06 20 42 TZD 37°29.3' GHA 158°37.5' Cal LHA 338°27.1' Obs long 179°49.6'E Az 144.0° PL 054.0° - 234.0°

Exercise 20 - Intercept Planet (page 132)

1 GMT 29d 23h 44m 02s LHA 045°05.3' TZD 41°27.9' CZD 41°24.8' Int 03.1' Away Az 260.0° PL 170.0° - 350.0° (T).
2 GMT 23d 04h 11m 00s LHA 328°05.0' TZD 35°13.2' CZD 35°17.4' Int 04.2' Towards Az 060.4° PL 150.4° - 330.4° (T).
3 GMT 16d 23h 39m 38s LHA 311°40.5' TZD 70°22.2' CZD 70°29.6' Int 07.4' Towards Az 132.5° PL 042.5° - 222.5° (T).
4 GMT 02d 06h 20m 42s LHA 338°39.5' TZD 37°29.3' CZD 37°22.4' Int 06.9' Away Az 144.0° PL 054.0° - 234.0° (T).
5 GMT 01d 12h 23m 34s LHA 046°22.5' TZD 43°44.4' CZD 43°49.7' Int 05.5' Towards Az 275.3° PL 005.3° - 185.3° (T).

Exercise 21 - Ex-mer alt Planet (page 135)

1 GMT 04d 00h 18m 00s LHA 004°09.7' TZD 29°22.0' MZD 29°08.1' Obs lat 40°08.0'N Az 188.3° PL 098.3° - 278.3° (T)
2 GMT 30d 08h 59m 44s LHA 008°12.3' TZD 74°05.0' MZD 73°45.5' Obs lat 56°00.9'N Az 188.1° PL 098.1° - 278.1° (T)
3 GMT 14d 13h 16m 20s LHA 004°11.7' TZD 40°56.8' MZD 40°51.1' Obs lat 64°00.0'N Az 185.9° PL 095.9° - 275.9° (T)
4 GMT 17d 01h 27m 20s LHA 008°23.3' TZD 53°00.0' MZD 52°27.6' Obs lat 45°04.3'S Az 349.6° PL 079.6° - 259.6° (T)
5 GMT 04d 10h 58m 00s LHA 002°07.4' TZD 36°00.8' MZD 35°58.4' Obs lat 52°09.6'S Az 356.5° PL 086.5° - 266.5° (T).

Exercise 22 - Amplitude Moon (page 138)

GMT	h	m	T Amp	Err	Dev
1	02	06	02	288.7°	1.3°W	1.7°E
2	31	20	48	105.7°	3.7°E	2.0°E
3	05	02	07	089.0°	9.0°E	1.0°W
4	02	18	54	242.8°	17.2°W	5.2°W
5	21	17	30	079.7°	0.3°W	5.0°E

Exercise 23 - Mer alt Moon (page 139)

	GMT	d	h	m	MZD	Obs lat	PL
1	Dec	01	06	15	32° 42.2'	40° 09.3'S	E-W
2	July	21	11	05	27° 55.4'	37° 25.2'N	E-W
3	Feb	26	02	18	25° 31.2'	50° 07.6'S	E-W
4	Sept	02	04	35	65° 44.0'	45° 16.2'N	E-W
5	Nov	30	01	46	27° 40.5'	40° 11.2'S	E-W

Exercise 24 - Azimuth Moon (page 142)

GMT	h	m	s	LHA	T Az	Err	Dev
1	20	07	42	00	291° 46.0'	091.1°	8.9°W	2.9°W
2	31	08	12	50	050° 01.7'	233.4°	3.4°E	6.4°E
3	30	18	50	00	046° 33.0'	276.5°	3.5°W	7.0°W

Exercise 25 - Long by chron - Moon (page 145)

1 GMT 02d 02 46 37 TZD 55°41.0' GHA 158°44.6' Cal LHA 038°16.3' Obs long 120°28.3'W Az 224.8° PL 134.8 - 314.8°

2 GMT 22d 00 24 49 TZD 44°37.6' GHA 248°08.5' Cal LHA 324°51.0' Obs long 076°42.5'E Az 051.1° PL 141.1° - 321.1°

3 GMT 06d 14 33 32 TZD 45°14.0' GHA 016°07.9' Cal LHA 315°23.4' Obs long 060°44.5'W Az 078.1° PL 168.1 - 348.1°

4 GMT 25d 03 11 20 TZD 43°15.7' GHA 321°11.7' Cal LHA 048°26.2' Obs long 087°14.5'E Az 271.7° PL 001.7° - 181.7°

5 GMT 30d 23 10 10 TZD 49°21.2' GHA 091°58.8' Cal LHA 311°35.1' Obs long 140°23.8'W Az 076.9° PL 166.9 - 349.9°

Exercise 26 - Intercept - Moon (page 148)

1 GMT 06d 14h 33m 32s LHA 315°17.9' TZD 45°14.0' CZD 45°19.4' Int 05.4' Towards Az 078.1° PL 168.1° - 348.1° (T).

2 GMT 30d 23h 10m 10s LHA 311°38.8' TZD 49°21.2' CZD 49°17.9' Int 03.3' Away Az 076.9° PL 166.9° - 349.9° (T).

3 GMT 02d 02h 46m 37s LHA 038°25.6' TZD 55°41.0' CZD 55°47.1' Int 06.1' Towards Az 224.8° PL 134.8° - 314.8° (T).

4 GMT 22d 00h 24m 49s LHA 324°58.5' TZD 44°37.6' CZD 44°31.9' Int 05.7' Away Az 051.1° PL 141.1° - 321.1° (T).
5 GMT 25d 03h 11m 20s LHA 048°22.7' TZD 43°15.7' CZD 43°12.8' Int 02.9' Away Az 271.7° PL 001.7° - 181.7° (T).

Exercise 27 - Ex-mer alt - Moon (page 152)

1 GMT 02d 04h 01m 26s LHA 356°42.3' TZD 60°20.2' MZD 60°15.5' Obs lat 39°50.4'N Az 176.4° PL 086.4° - 266.4° (T)
2 GMT 26d 07h 01m 30s LHA 003°56.6' TZD 20°34.3' MZD 20°19.3' Obs lat 44°58.4'S Az 349.8° PL 079.8° - 259.8° (T)
3 GMT 06d 17h 01m 28s LHA 351°49.2' TZD 37°28.8' MZD 36°48.8' Obs lat 45°44.4'N Az 166.6° PL 076.6° - 256.6° (T)
4 GMT 01d 10h 58m 49s LHA 354°30.4' TZD 40°00.0' MZD 39°43.1' Obs lat 46°17.6'S Az 008.5° PL 098.5° - 278.5° (T)
5 GMT 23d 21h 40m 30s LHA 003°07.7' TZD 49°01.1' MZD 48°57.5' Obs lat 57°56.9'N Az 184.1° PL 094.1 - 274.1° (T).

Exercise 28 - Simple errors in sights (page 182)

1 Answer (i) Int 2.4' Towards. Answer (ii) Obs long 109° 1.4'W
2 Observed long 149° 17.2'E
3 Observed lat 52° 47.4'S
4 Answer (i) Obs long 79° 34.9'E. Answer (ii) Int 5.4' Towards
5 Answer (i) Int 3.3' Away. Answer (ii) Obs long 133° 55.4'W

Exercise 29 - Computation of altitudes (page 187)

1: 85°05.9' 2: 18°26.3' 3: 56°00.9' 4: 62°01.3' 5: 46° 50.8'
6: 36°18.7' 7: 57°47.5' 8: 36°03.4' 9: 44°23.5' 10: 40° 22.1'

Exercise 30 - Star identification (page 192)

	GMT	d	h	m	s	Approx dec	SHA ★	Name of ★
1	Sept	22	12	51	32	19° 27.6'N	146° 46.2'	Arcturus
2	Aug	31	00	20	26	17° 53.2'S	349° 31.0'	Diphda
3	Nov	29	11	29	20	08° 16.9'S	281° 27.0'	Rigel
4	Jan	19	07	33	44	07° 18.7'N	271° 16.2'	Betelgeuse
5	April	30	20	51	23	16° 50.7'S	258° 50.4'	Sirius

Exercise 31 - Great Circle Sailing (page 208)

	Initial Co	Final Co	Dist	Lat of V	Long of V
1	S45°50.6'W	S77°40.7'W	2403.1	51°44.5'S	154°43.8'E
2	S81°28.2'E	S29°08.5'E	2297.4	69°44.2'N	051°44.1'E
3	N39°14.3'W	N54°24.5'W	4084.8	51°28.1'N	111°55.6'E
4	N89°02.8'W	S49°52.0'W	2769.5	49°50.4'N	006°29.8W
5	S13°52.8'E	N14°05.1'E	5958.2	79°15.4'S	061°09.7'E
6	N58°49.6'E	N89°34.9'E	3347.5	36°00.1'N	005°17.2W
7	48°54.5'S	8: 158°04.4'W	9: 51°25.0'W	10: 30°50.9'N	

Exercise 32 - Composite Circle Sailing (page 212)

	Initial Co	Final Co	Long of V	Long of W
1	S55°30.5'E	N61°10.1'E	145°31.0'W	111°53.9'W

Distance = 1725.4 + 1157.0 + 1360.3 = 4242.7 Miles

2	S40°02.7'W	N40°44.7'W	42°07.6'W	080°58.6'W

Distance = 2603.5 + 1165.5 + 2524.7 = 6293.7 Miles

3	N63°29.7'W	S60°30.1'W	161°48.0'W	174°51.9'W

Distance = 1794.8 + 554.3 + 2067.2 = 4416.3 Miles

4 Long M 178° 57.3'W 5 Lat N 44° 53.1'N

Exercise 33 - Stars suitable for observation (page 224)

1 GMT 06d 13h 27m 00s SHA 278° 13.2' ± 30° Stars: Sirius, Canopus, Betelgeuse, Capella, Rigel.

2 GMT 14d 02h 41m 36s SHA 092° 55.1' ± 45° Stars: Deneb, Altair, Vega, Kaus Australis, Atria, Shaula, Antares.

3 GMT 16d 19h 27m 00s SHA 138° 15.4' ± 40° Stars: Rigel-Kent, Arcturus, Hadar. Planet: Venus

4 GMT 30d 12h 59m 00s SHA 196° 06.0'. Star Dubhe is within 8 minutes from mer pass. Ex-mer limit is approx. 29 minutes.

5 GMT 23d 08h 47m 00s SHA 081° 47.8' ± 30° Stars: Altair, Vega, Kaus Australis, Shaula, Atria. Note: Vega is within 4 mins of mer pass. Ex-mer limit is large - Ex-mer alt possible.

-o0o-

SUMMARY OF FORMULAE FOR CALCULATOR USE

Amplitude

$$\text{Sin Amp} = \frac{\text{Sin dec}}{\text{Cos lat}}$$

Azimuth

$$A = \frac{\text{Tan lat}}{\text{Tan P}} \qquad B = \frac{\text{Tan dec}}{\text{Sin P}} \qquad \text{Tan Az} = \frac{1}{\text{C . Cos lat}}$$

Rules for naming A, B, C and Az are as given in nautical tables.

If LHA between 000° and 180°, P = LHA
If LHA between 180° and 360°, P = 360 - LHA

Longitude by chronometer

$$\text{Cos P} = \frac{\text{Sin T alt} \mp \text{Sin lat . Sin dec}}{\text{Cos lat . Cos dec}}$$

If Lat and dec are same name (-), contrary names (+).
Hence in the formula, (-) has been put above the (+).
Entire numerator is Sin while entire denominator is Cos.

Intercept

$$\text{Cos CZD} = \text{Cos P . Cos lat . Cos dec} \pm \text{Sin lat . Sin dec}$$

If Lat and dec are same name (+), contrary names (-).
Hence in the formula, the (+) has been put above the (-).
The <u>signs</u> are <u>opposite to</u> that for <u>long</u> by <u>chron formula</u>.

Ex-meridian altitude

$$\text{Cos MZD} = \text{Cos TZD} + [(1 - \text{Cos P}) \text{ . Cos DR lat . Cos dec}].$$