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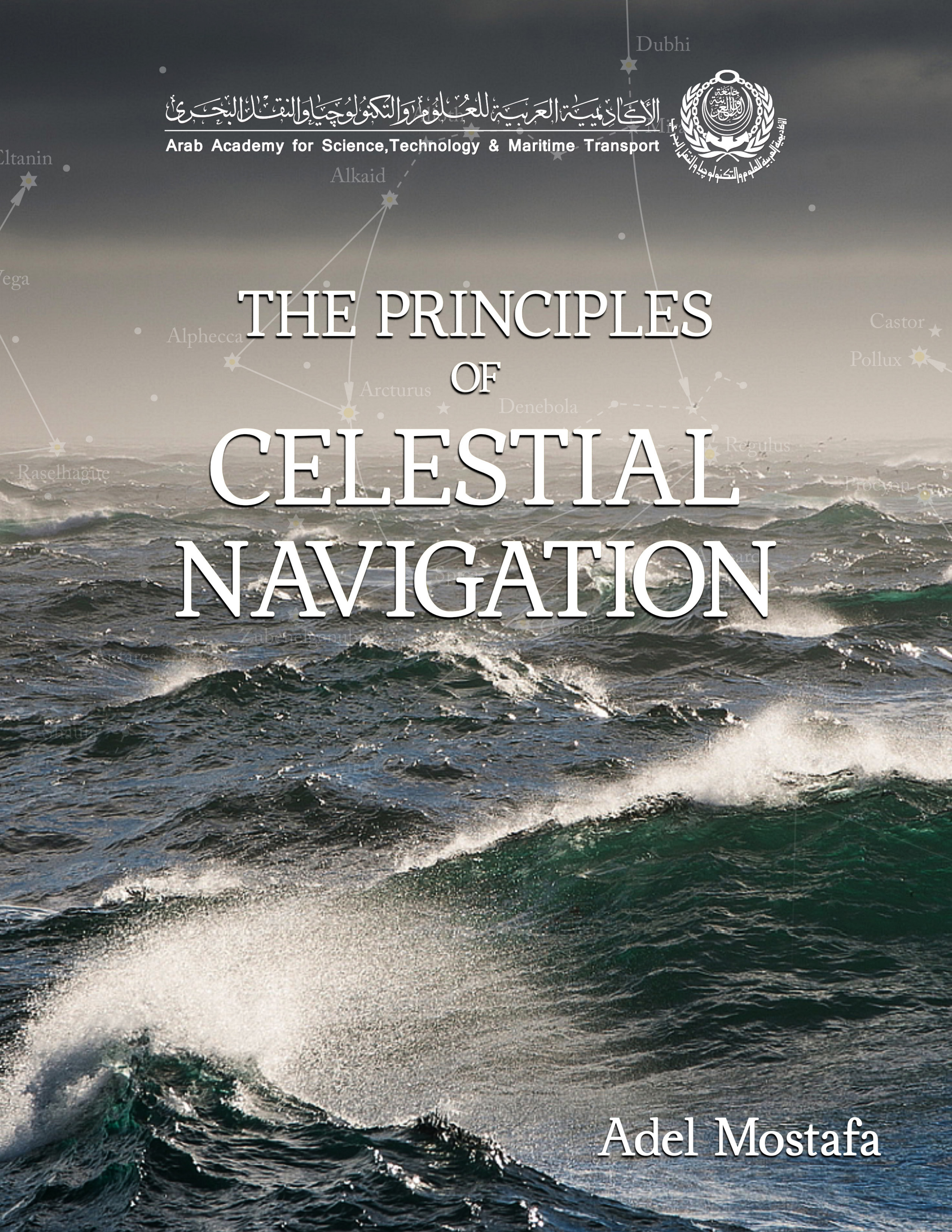
Arab Academy for Science, Technology & Maritime Transport



THE PRINCIPLES OF CELESTIAL NAVIGATION

Adel Mostafa

THE PRINCIPLES OF CELESTIAL NAVIGATION

Table of contents

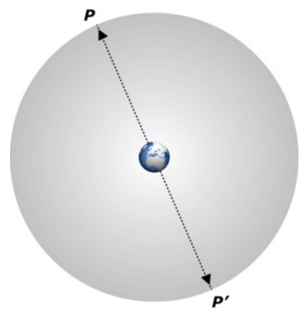
The Concept of the Celestial Sphere

The Celestial Sphere

It is assumed that all heavenly bodies are moving on the inner surface of an imaginary huge sphere, centered at the earth's center and of radius infinity. This sphere is known as the Celestial Sphere.

Celestial Poles

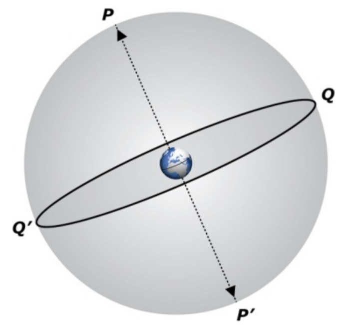
The axis of rotation of the earth when extended to infinity from each side, will meet the celestial sphere in two points; the north celestial pole (P) and south celestial pole (p`).



Note:

- The extension of the Earth`s axis of rotation is the *Axis of Rotation* of the celestial sphere.

- The Celestial Sphere appears to rotate from *East to West* as a reverse rotation of the Earth`s rotation from *West to East.* This is the reason of why the Sun rises and sets daily.

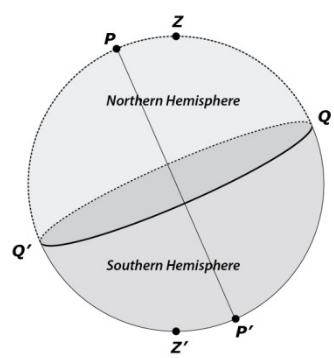


The Equinoctial or Celestial Equator

The great circle on the celestial sphere which is perpendicular to the axis of rotation is known as the Equinoctial.

Note:

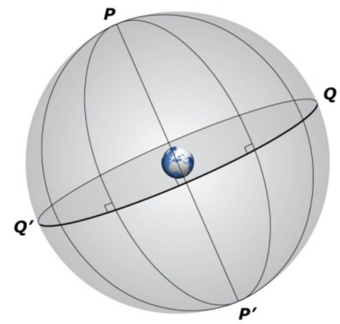
The Equinoctial divides the celestial sphere into *Northern and Southern* hemispheres



Celestial Meridians

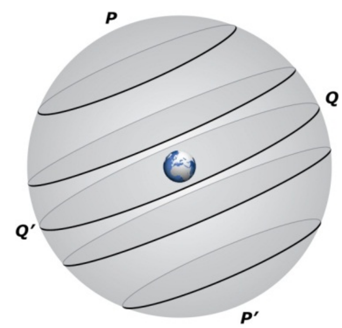
The semi-great circle on the celestial sphere which joins the poles are known as the Celestial Meridians or hour circles.

Note:
Celestial meridians are perpendicular to the Equinoctial



Parallels of Declinations

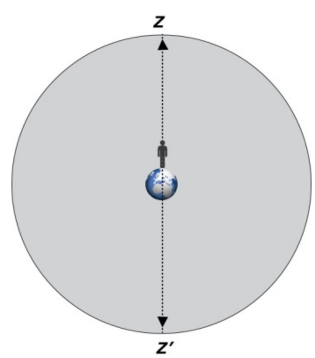
The small circles on the celestial sphere which are parallel to the Equinoctial are known as the parallels of declinations or diurnal circles.



Zenith and Nadir points

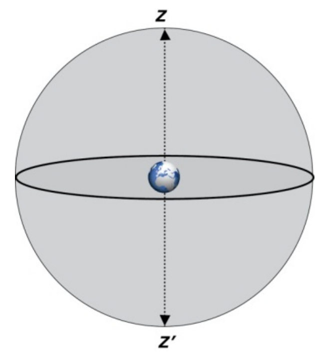
The radius of the earth when extended to infinity passing through the observer, meets the celestial sphere at two points: the most upper point Zenith (Z) and the most lower point Nadir (Z`).

Note:
According to definition, every observer on the earth`s surface has its own zenith point (and of course nadir point).



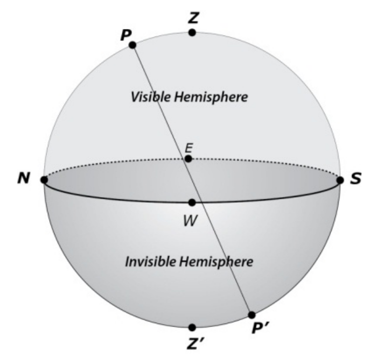
Horizon circle

The great circle on the celestial sphere which is perpendicular to the line joining the Zenith and Nadir points is known as the horizon circle.



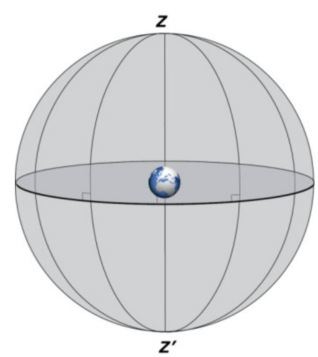
Note:

- The horizon circle divides the celestial sphere into *Visible and Invisible* hemispheres.
- Before Sunrise and after Sunset, Sun is not seen, because it is in the invisible hemisphere.



Vertical circles

The Semi-great circles on the celestial sphere which joins the zenith and nadir points are known as the Vertical Circles.

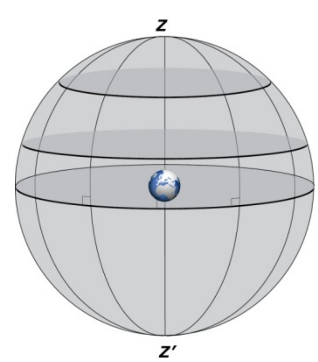


Note:

The vertical circles are perpendicular to the horizon circle.

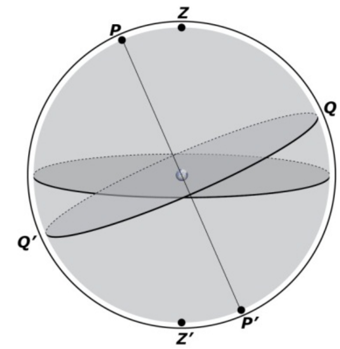
Parallels of Altitude

The small circles on the celestial sphere which are parallel to the horizon circle are known as parallels of altitude.



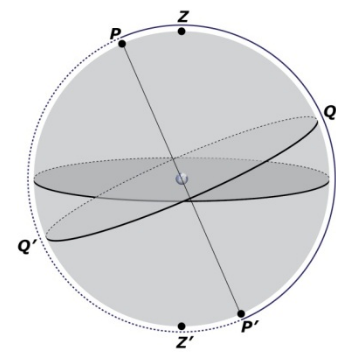
The Observer's Meridian

The great circle on the celestial sphere which passes through the Poles, Zenith and Nadir points is known as the Observer's Meridian



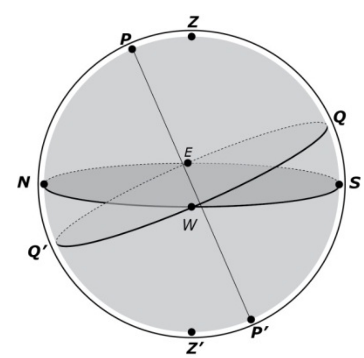
Note:
The Observer's Meridian is divided into:

- Upper Observer's Meridian; passes through the Poles and Zenith point, i.e. (PZP`).
- Lower Observer's Meridian; passes through the Poles and Nadir point, i.e. (PZ`P`).



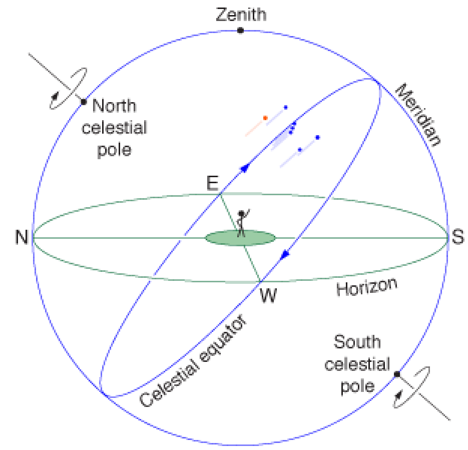
The principle vertical circle

The great circle on the celestial sphere which passes through zenith, nadir and the celestial poles is known as the Principle Vertical Circle.



Note:
The principle vertical circle is the same circle defined before as the observer's meridian.

The Cardinal points

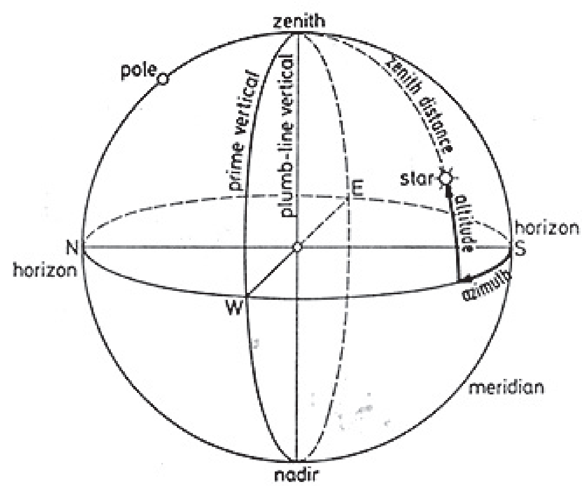


The principle vertical circle intersects the horizon in two points, the nearest point to the north celestial pole P is the North point (N) and the nearest point to the south celestial pole P` is the South point (S) . East point (E) and west point (W) are put on the horizon circle according to the well-known arrangement.

Note:

The principle vertical circle or the observer's meridian divides the celestial sphere into *Eastern and Western* hemi-spheres.

The Prime Vertical Circle



The great circle on the celestial sphere that passes through zenith, nadir, East, and West points is known as the Prime Vertical Circle.

Note :

- The principle vertical circle.
- The prime vertical circle.
- The horizon circle.

Are three perpendicular great circles.

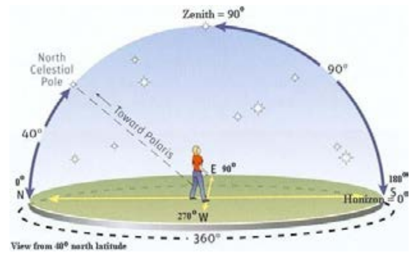
Amplitude

It is the arc on the horizon; from the East point E or the west point W to the rising point or setting point of the celestial body respectively.
It is measured from 00° to 90°. It is calculated by the following relation:

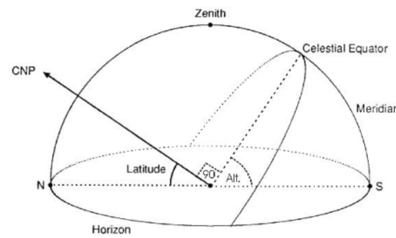
$$\text{Sin Amp.} = \text{Sin Dec. Sec Lat.}$$

Elevation of the Pole:

The elevation of the Pole above the horizon circle of a certain observer; is *equal* to the Latitude of that observer.

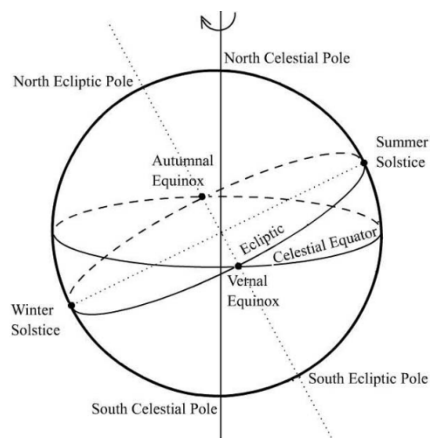


Thus, for an observer in latitude 40° N, the north pole will be elevated 40° above the north point N, and for an observer in Latitude 50° S, the south pole will be elevated 50° above the south point S.



Ecliptic Circle:

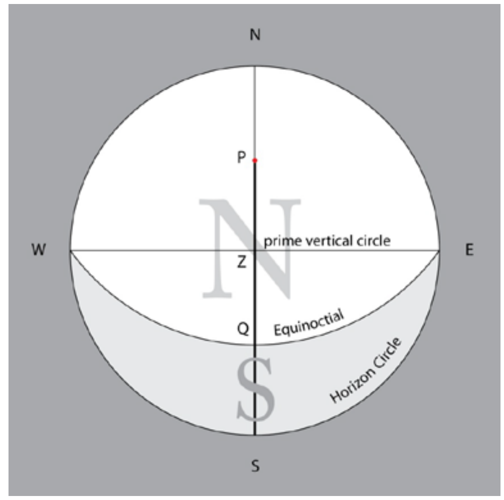
It is the apparent annual path of the Sun among the stars. It is a great circle inclined to the Equinoctial by about 23°.5; and intersects the Equinoctial in two points; Vernal Equinox (γ) and Autumnal Equinox. This will be discussed in details later.



Horizon plane projection

Celestial Sphere Projected on the Horizon Plane has two cases:

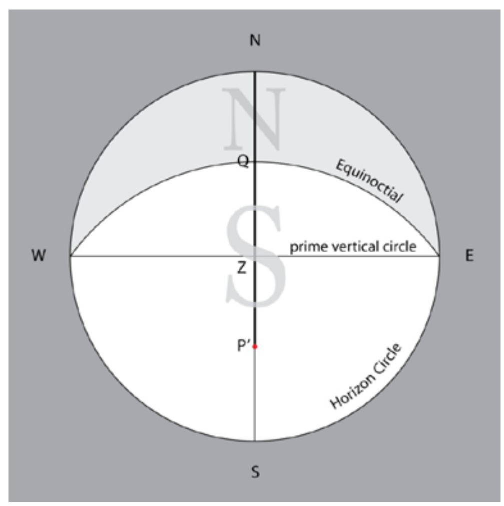
A. Celestial Sphere Projected on the Horizon Plane for a ***North Latitude*** Observer:



In the figure:

NESW; is the Horizon Circle.
P is the North Pole
Z is the Zenith point
NP is the visible part of the Lower observer`s meridian.
PZQS is the visible part of the Upper observer`s meridian**.**
EZW is the half of the Prime vertical circle seen above the horizon .
EQW is the half of the Equinoctial seen above the horizon .

B. Celestial Sphere Projected on the Horizon Plane for a ***South Latitude*** Observer:



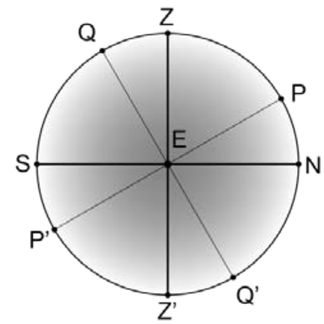
In the figure :

NESW; is the Horizon Circle.
P` is the South Pole
Z is the Zenith point
SP` is the visible part of the Lower observer`s meridian.
P`ZQN is the visible part of the Upper observer`s meridian
EZW is the half of the Prime vertical circle seen above the horizon.
EQW is the half of the Equinoctial seen above the horizon.

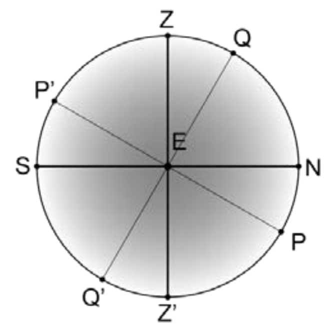
Observer`s Meridian Plane Projection

Celestial Sphere Projected on the Observer`s Meridian has four cases:

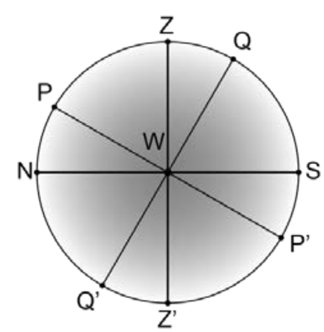
A. Eastern hemisphere for North latitude observer



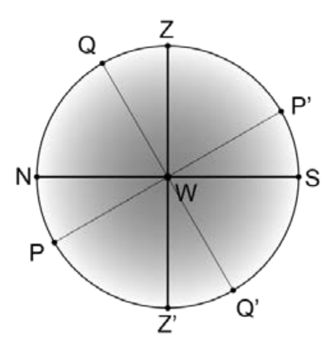
B. Eastern hemisphere for South latitude observer



C. Western hemisphere for North latitude observer



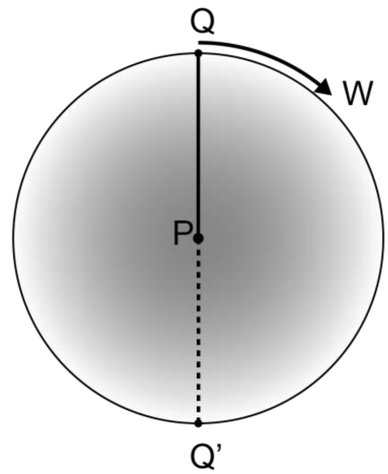
D. Western hemisphere for South latitude observer



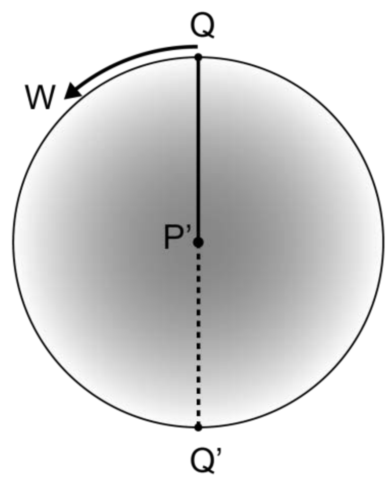
Equinoctial Plane Projection

Celestial Sphere Projected on the Equinoctial plane has two cases:

A. As seen from the North Pole.

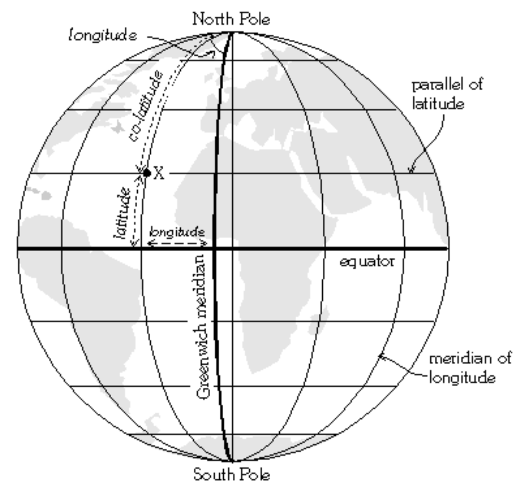


B. As seen from the South Pole.



Systems of Coordinates

Systems of coordinates on the celestial sphere



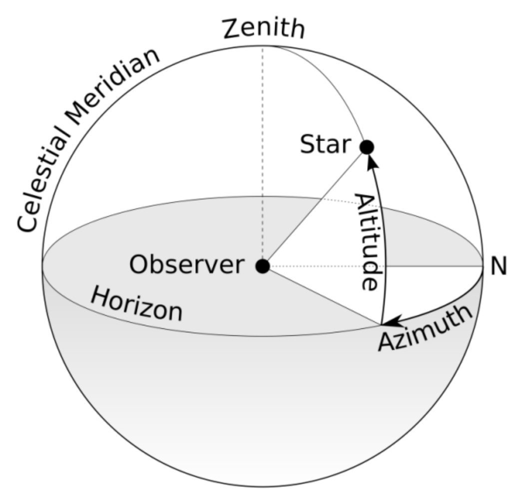
In geography and navigation; the coordinates of various points of earth's surface are found from their relationship to two mutually perpendicular great circles. The *Equator* and the *Greenwich meridian*.

The same method is employed for developing coordinate systems of the celestial bodies on the celestial sphere. Systems are chosen of two mutually perpendicular great circles that occupy very definite positions on the celestial sphere

We shall define three systems of coordinates used in Celestial Navigation;

- ***A. The Horizon system of coordinates***
- ***B. The 1st Equatorial system of coordinates***
- ***C. The 2nd Equatorial system of coordinates***

A. The Horizon system of coordinates:



The Mutual perpendicular great circles used in this system are:

- Horizon circle.
- Principle vertical circle.

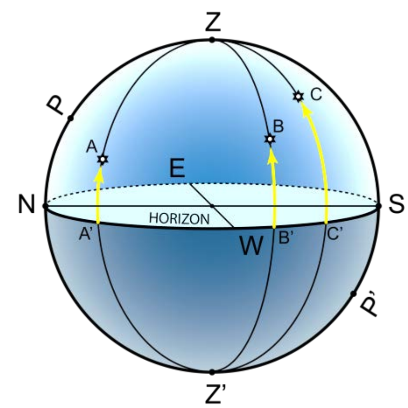
And the related elements of coordinates are:

- Altitude or (zenith distance).
- Azimuth.

Altitude of a heavenly body:

It is an arc on the vertical circle of the celestial body; from the horizon circle to the body; and measured from 0˚ to 90˚.

Note: Altitude is symbolic (h).



Meridian Altitude:

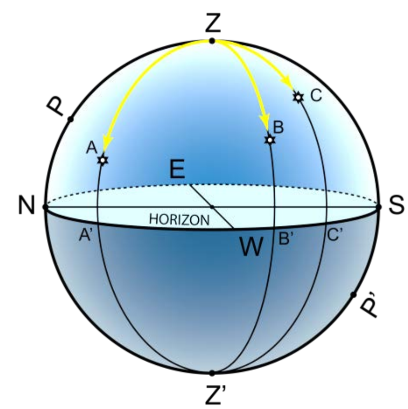
At the instance of meridian passage, the altitude of the heavenly body is said to be meridian altitude.

Note: Meridian altitude is symbolic as (H) and denoted N or S according to the nearest point of the horizon.

Zenith Distance of a heavenly body:

It is an arc on the vertical circle of the heavenly body; from the zenith point to the body; and measured from 0˚ to 90˚.

Note: Zenith distance is symbolic (z).



Meridian Zenith Distance:

At the instance of meridian passage, the zenith distance of the heavenly body is said to be meridian zenith distance.

Note: Meridian zenith distance is symbolic (Z).

Relation between Altitude and Zenith Distance:

Regarding the figure; we conclude the following:

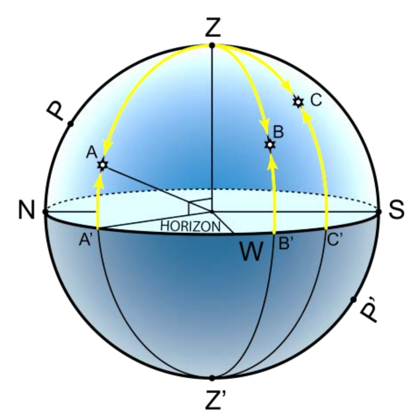
X\`X is the altitude of the body X

ZX is the zenith distance of the body X

Since: X\`X + ZX = 90˚

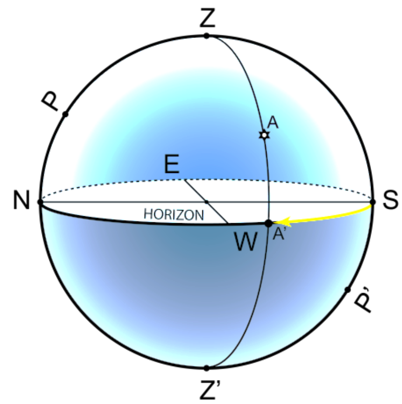
Therefore:

$$\boxed{\text{Alt.}_* + \text{ZD}_* = 90^\circ}$$



Azimuth:

It is the arc on the horizon circle (or the angle at zenith point) from the principle vertical circle to the vertical circle of the heavenly body, and measured in 3 ways:

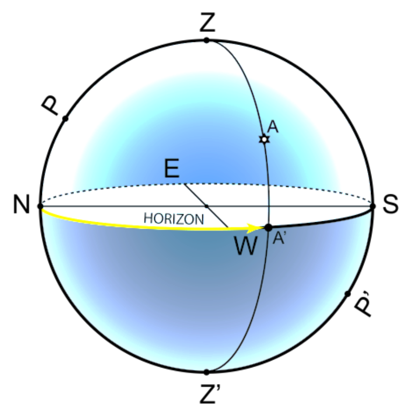


Quadratic measuring:

Where the Azimuth is reckoned from <u>*0° to 90°*</u> *starting from N or S point in East or West direction.*

Note:
Az. in figure ≈ S 49° W

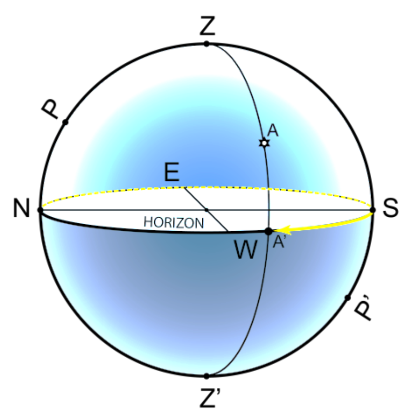
Semi-circular measuring:



Where the Azimuth is reckoned from <u>*0° to 180°*</u> *starting from N or S point (according to the latitude of the observer) in East or West direction.*

Note:
Az. in figure ≈ 151° NW

Circular measuring:



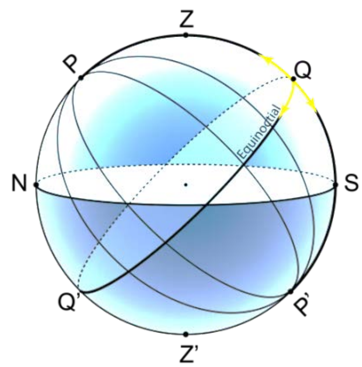
Where the Azimuth is reckoned from <u>*0° to 360°*</u> *starting from N point in Eastward direction and written in 3 figures notation. This is known as the True Bearing.(T. Bg.).*

Note:
Az. in figure ≈ 229°
Azimuth is symbolic (Az.).

The 1st Equatorial system of coordinates:

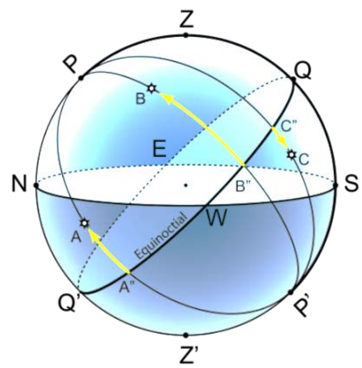
Mutual perpendicular great circles are:
- Equinoctial circle.
- The observer's meridian.

Elements of coordinates are:
- Declination or (Polar distance).
- Local hour angle.

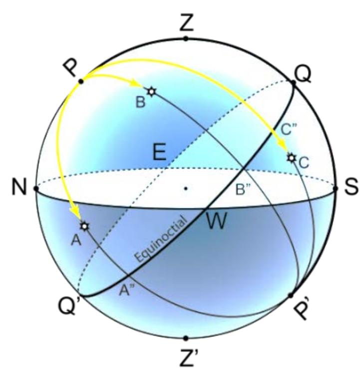


Declination of a heavenly body:

It is an arc on the meridian of a heavenly body; from the equinoctial to the body. It is measured from 0˚ to 90˚ N or S and it is symbolic (δ).



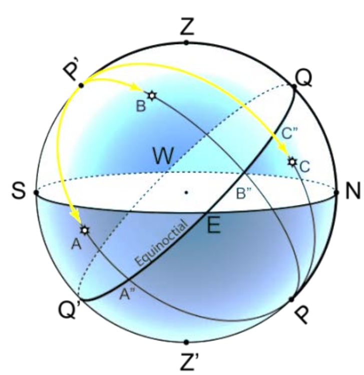
Note:
Declination of a heavenly body must be denoted N or S in accordance to the hemisphere in which it is situated.



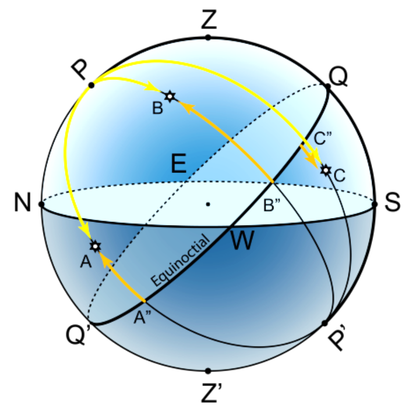
Polar Distance of a heavenly body:

It is an arc on the meridian of a heavenly body; from the <u>elevated pole</u> to the body. It is measured from 0˚ to 180˚and it is symbolic (Δ).

Note: The elevated pole is:
- N pole (P) for North observer.
- S pole (P') for South observer



Relation between Polar distance and Declination of a heavenly body:



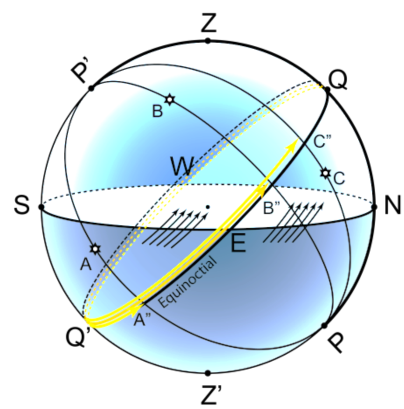
Polar distances measured from the elevated pole which is similar name to latitude. The polar distance is related to the declination as follows:

Polar Dist. = 90 ± Dec.

Note:

- Sign (+) is used if Latitude and Declination are of different names.
- Sign (--) is used if Latitude and Declination are of same names.

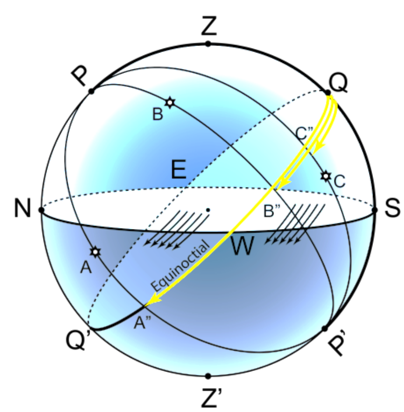
Local Hour Angle [LHA] of a heavenly body:



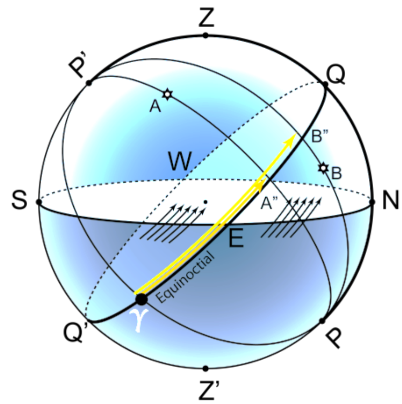
It is an arc on the equinoctial or an angle at the pole; starting from the upper meridian of the observer to the meridian of the heavenly body; and it is measured westerly from 0 to 360 ˚.

__Note:__

- A celestial body on the upper meridian has 360 ˚ L.H.A.
- A celestial body on the Lower meridian has 180 ˚ L.H.A.



The 2nd Equatorial system of coordinates:

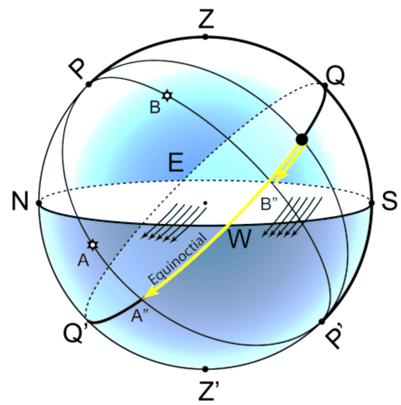


Mutual perpendicular great circles are:

- Equinoctial circle.
- Meridian of vernal equinox point (ϒ).

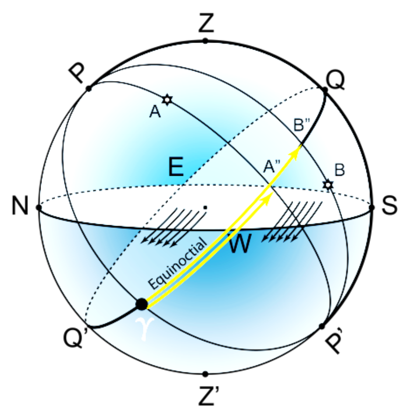
Elements of coordinates are:

- Declination (or Polar distance) as in the 1st Equatorial system.
- Sidereal hour angle (or Right Ascension).



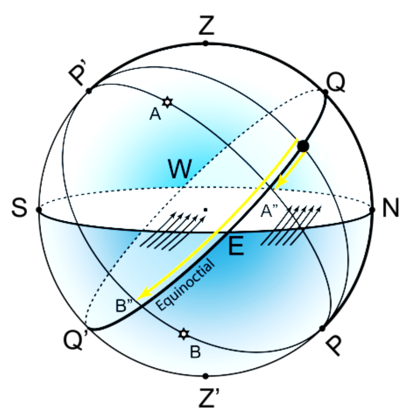
Sidereal Hour Angle (S.H.A.) of a heavenly body:

It is an arc on the equinoctial; starting from the meridian of the vernal equinox point to the meridian of the heavenly body. It is measured Westerly from 0˚ to 360˚.



Right Ascension (R.A.) of a heavenly body:

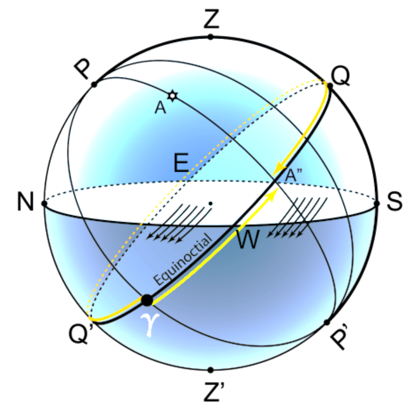
It is an arc on the equinoctial starting from the meridian of the vernal equinox point to the meridian of the heavenly body. It is measured Easterly from 0h to 24 h.

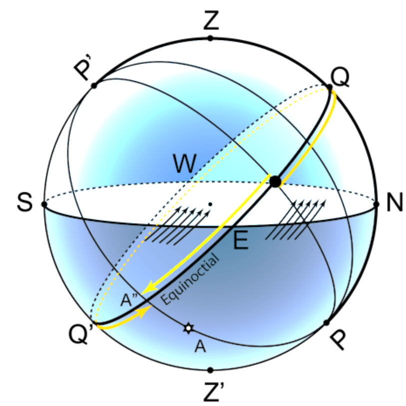


Relation between S.H.A. and R.A. of a heavenly body:

♈ X`` in <u>Westward</u> direction is S.H.A (Sidereal Hour Angle) of the body X
♈ X`` in <u>Eastward</u> direction is R.A (Right Ascension) of the body X
So we have:

$$S.H.A_{*} + R.A._{*} = 360° \text{ or } 24 \text{ h}$$

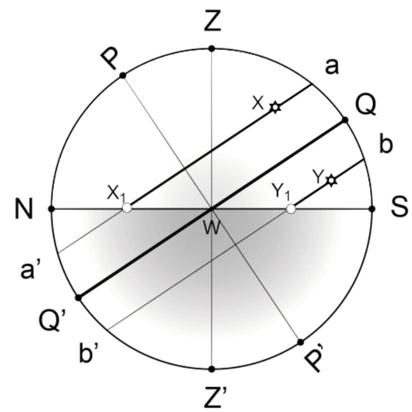




Apparent Diurnal Motion

The necessary Condition for rising and setting phenomena

For a heavenly body to rise and set, the parallel of declination of that body must cut the horizon circle.



In the figure, the parallels of declination of each of body X and body Y cuts the horizon circle in X_1 and Y_1 respectively. Thus for the bodies X and Y, The necessary condition to rise and set is:

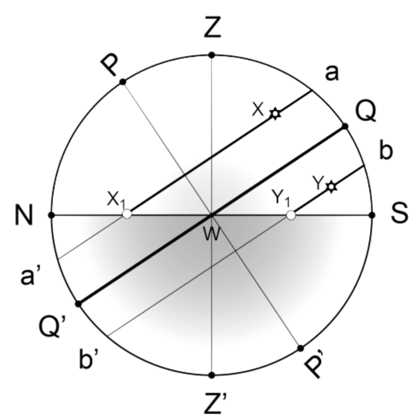
For body X : Q\` a\` < Q\` N i.e. Dec.< (90-lat)

For body Y : Q b < Q S i.e. Dec.< (90-lat)

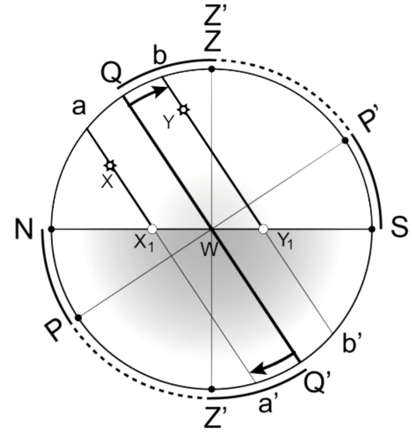
Thus the necessary condition for a celestial body to *Rise and Set* is:

Dec. + Lat. < 90

The necessary condition of a heavenly body to be above the horizon for an interval greater than below or vice versa :



Regarding figure ( ); which represents the celestial sphere of <u>north latitude</u> observer ; the heavenly body X of N. Dec.; and the heavenly body Y of S. Dec.;
We notice that the body X being above the horizon for an interval greater than below and the body Y being above the horizon for an interval less than below.



Regarding figure ( ); which represents the celestial sphere of <u>south latitude</u> observer ; the heavenly body X of N. Dec. and the heavenly body Y of S. Dec.;
We notice that the body X being above the horizon for an interval less than below and the body Y being above the horizon for an interval greater than below.
From above analysis we conclude the following rules:

If [Lat. + Dec. < 90 ; and lat. Is **<u>same name</u>** as Dec.] →
Rising interval > setting interval

If [Lat. + Dec. < 90 ; lat. Is **<u>contrary name</u>** to Dec.] →
Rising interval < setting interval

The necessary condition for a heavenly body to be circumpolar

For a heavenly body to be circumpolar; it`s parallel of declination does not intersect the horizon

In the figure, the parallel of declination of the body X is completely above the horizon whilst that of the body Y is completely below the horizon.

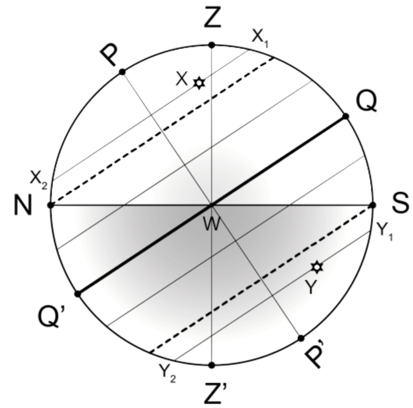
Thus the necessary conditions for the heavenly bodies X & Y to be circumpolar are:

For X: Q` a` $\geq$ Q` N i.e. Dec. $\geq$ (90 – Lat.)

For Y: Q b` $\geq$ Q S i.e. Dec. $\geq$ (90 – Lat.)

Thus the necessary condition is:

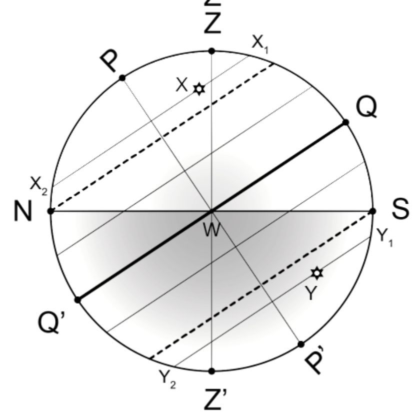
$$\text{Dec.} + \text{Lat.} \geq 90$$



The condition of a heavenly body to be circumpolar above or below the horizon

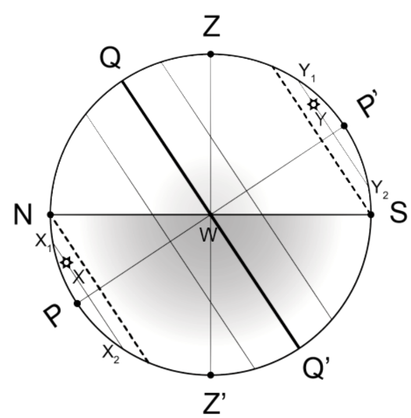
Regarding figure ( ); which represents the celestial sphere of north latitude observer; and the heavenly body X which has a N. Dec. and the heavenly body Y which has a S. Dec.

We notice that the heavenly body X being a circumpolar above the horizon and the heavenly body Y being a circumpolar below the horizon.



Regarding figure ( ); which represents the celestial sphere of south latitude observer ; and the heavenly body X which has a N. Dec. and the heavenly body Y which has a S. Dec.

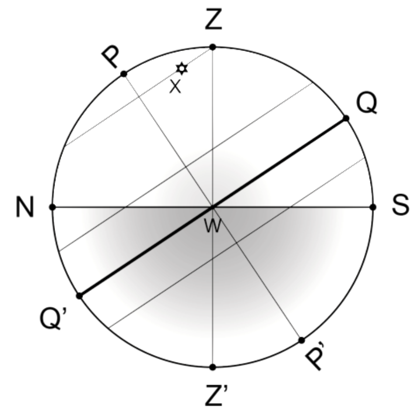
We notice that the heavenly body X being a circumpolar below the horizon and the heavenly body Y being a circumpolar above the horizon.



From above analysis we conclude the following rules:

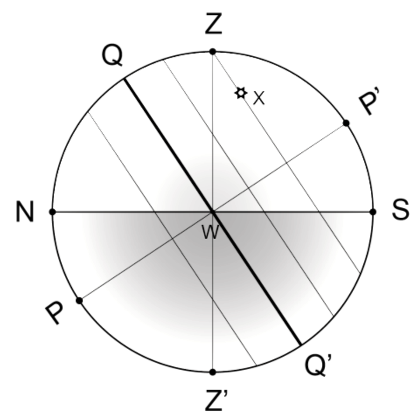
If [Lat. + Dec. ≥ 90 ; lat. same name as Dec.]
→ The heavenly body being a circumpolar above the horizon.

If [Lat. + Dec.≥ 90 ; lat. contrary name to Dec.]
→ The heavenly body being a circumpolar below the horizon.



The necessary condition for a heavenly body to cross the upper meridian at zenith point

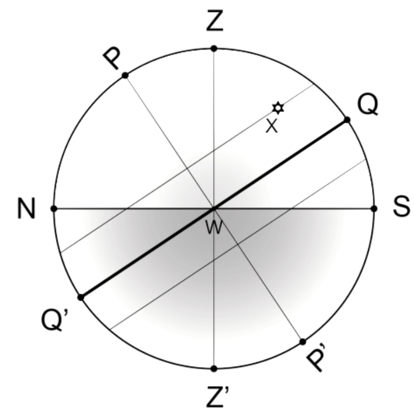
Regarding figure ( ); which represents the celestial sphere for a N latitude observer and heavenly body X of north declination equals the latitude of the observer; we notice that the heavenly body crosses the upper meridian at zenith point.



Regarding figure ( ); which represents the celestial sphere for a S latitude observer and heavenly body X of south declination equals the latitude of the observer ; we notice that the heavenly body crosses the upper meridian at zenith point .

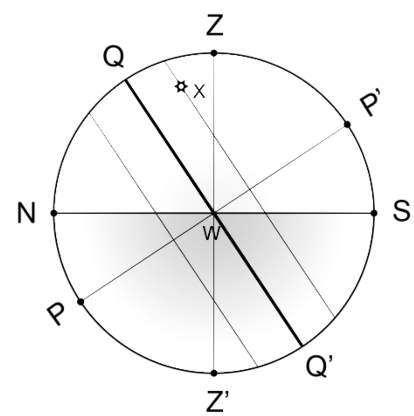
Thus the necessary conditions for a heavenly body to cross the zenith point are:

1. Declination = Latitude
2. Latitude. & Declination are same names.



The necessary condition for a heavenly body to cross the prime vertical circle above the horizon

Regarding figure ( ); which represents the celestial sphere for a N latitude_observer and heavenly body X of north declination less than the latitude of the observer ; we notice that the heavenly body crosses the prime vertical circle above the horizon.



Regarding figure ( ); which represents the celestial sphere for a S latitude_observer and heavenly body X of south declination less than the latitude of the observer ; we notice that the heavenly body crosses the prime vertical circle above the horizon.

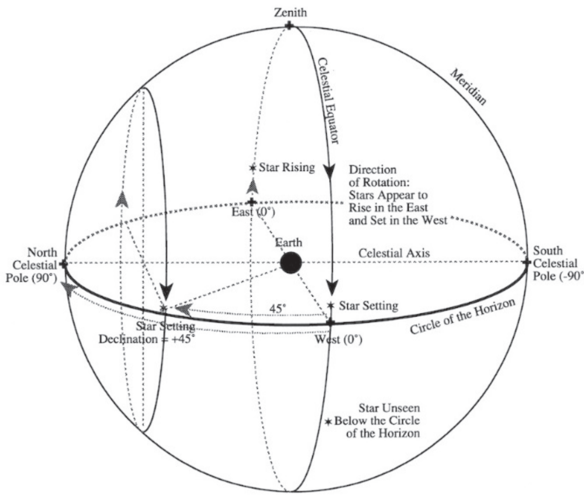
Thus the necessary conditions for a heavenly body to cross the prime vertical circle above the horizon are:

1. Declination = Latitude
2. Latitude. & Declination are same names.

Characteristics of the apparent diurnal motion for an observer on the Equator :

Regarding the figure; for an observer on the Equator we notice that, the North Pole coincides to the north point N; hence the South Pole coincides to the south point S. Also, we notice the following:

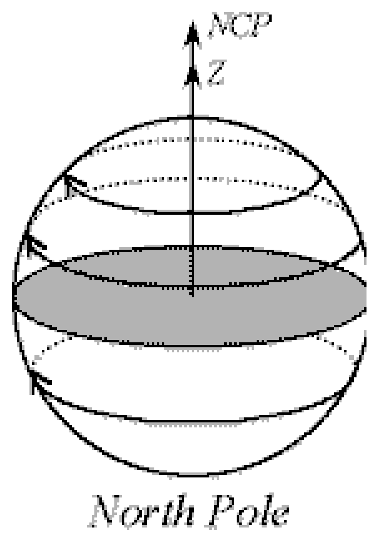
- The Equinoctial coincides to the Prime vertical circle.
- All the heavenly bodies rise and set.
- The Amplitude equals the declination of the heavenly body at the instance of its rise or set.
- The interval of being above the horizon equals the interval below for any heavenly body all-round the year.



Characteristics of the apparent diurnal motion for an observer at any of the earth`s poles:

Regarding the figure ; for an observer at any of the Poles ; we notice that, the similar celestial pole coincides to the zenith point Z , hence the other celestial Pole coincides to the nadir point Z` . Also, we notice the following:

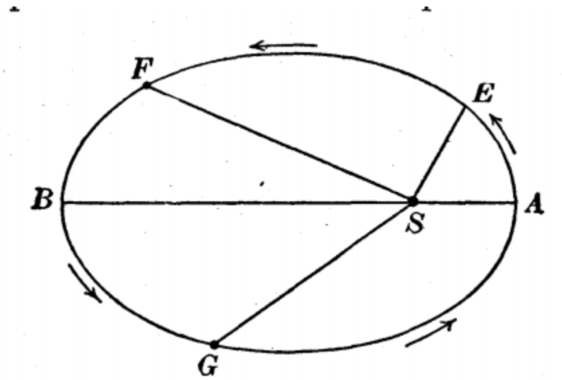
- The Equinoctial coincides to the Horizon circle.
- All the heavenly bodies are circumpolar.
- The altitude equals the declination of the heavenly body at any time.
- There are no cardinal points because the principle vertical circle is not defined.



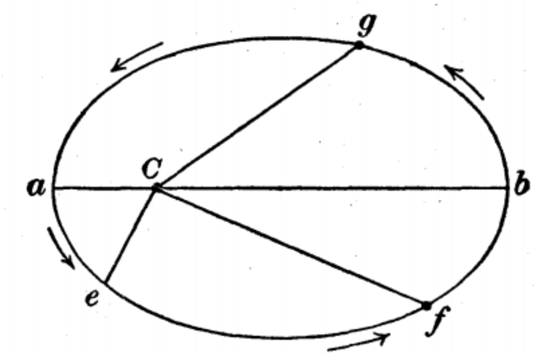
Apparent Annual Motion of the Sun

The Earth's orbit around the sun

The Earth is one of the solar system planets and revolving around the Sun in an elliptical orbit, whilst the Sun being situated at a focus S of that ellipse.



Since our observations are made from the Earth`s surface, the Sun appears to describe an apparent elliptical orbit around the Earth; C is the center of the Earth and the ellipse represents the apparent orbit of the Sun relative to the Earth.



The sequence of positions of the Sun, namely (a, e, f, b, g) in this orbit, corresponds the sequence of positions (A, E, F, B, G) of the Earth in its orbit around the Sun.

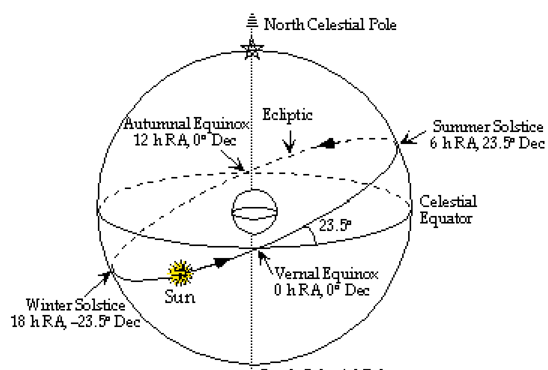
The closest distance between the two bodies is about 147 million Km. in January where the sun is said to be in Aphelion and the farthest is about 152 million km. in July where the sun is said to be in Perihelion.

The Ecliptic

In the course of the year, the Sun thus appears to make a complete circuit of the heavens against the background of the stars. The plane of that orbit is called the ecliptic.

The ecliptic is defined as:

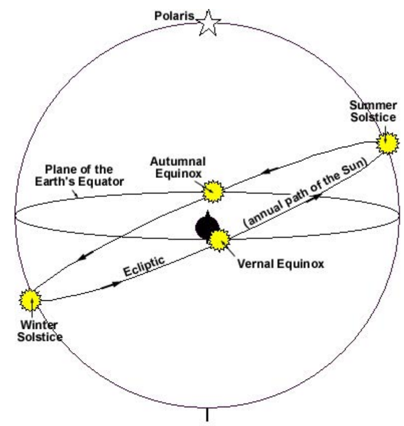
The apparent annual path of the true Sun among the stars. It is a great circle inclined at an angle of 23° 27´ (as a mean value) to the equinoctial.



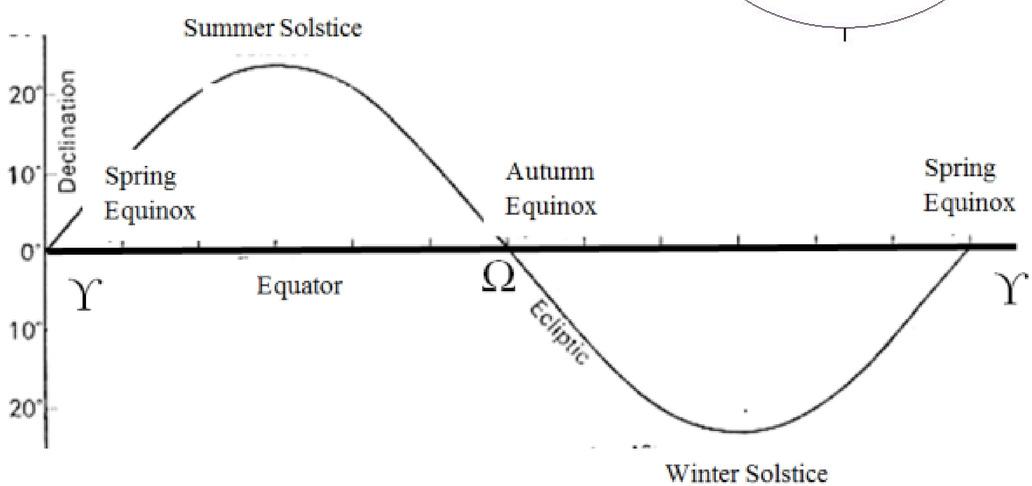
Ecliptic

Description of the apparent annual motion of the true Sun:

It has been pointed out .that the Sun makes a complete revolution around the ecliptic in roughly one year; 365 days, hence, the Sun covers about 1° a day along the ecliptic, which makes the night stars differs through the seasons.



Since the equinoctial divides the ecliptic in two halves, the Sun is in the northern hemisphere and has north declination half of the year whilst the other half it lies in the southern hemisphere and has south declination.



We notice that there are (4) significance points for the sun in its orbit ; two of them when crossing the Equinoctial known as the Equinoxes the others when reaching maximum distance from the Equinoctial known as the Solstices.

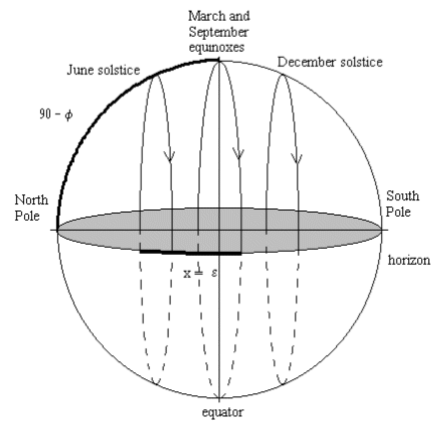
The table shows the names of these points, dates and the coordinates of the sun therefore.

Name of the point	Date	Dec.	R.A.	SHA
Vernal Equinox	21st Mar.	00°	0h	360°
Summer Solstice	21st Jun.	23° 27` N	6h	270°
Autumnal Equinox	23rd Sept.	00°	12h	180°
Winter Solstice	22nd Dec.	23° 27` S	18h	90°

Combination between annual motion and diurnal motion of the sun:

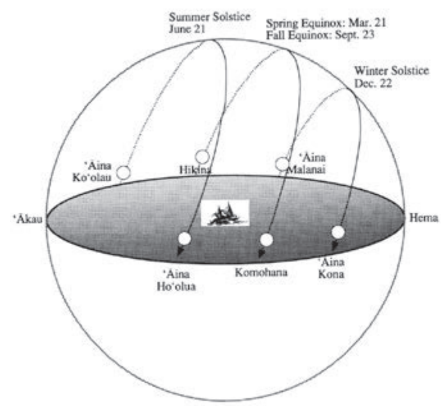
For an observer in the Equator (Latitude 00°):

- Day is always equal to night.
- Sun crosses zenith point Z twice a year at the dates of Equinoxes. i.e. on 21st March & 23rd Sept. when its declination is 00° .
- Sun reaches its maximum Amplitude 23° 27` at sunrise & sunset, twice a year at the dates of Solstices. (i.e. on 22nd Jun. & 22nd Dec. When its declination is 23° 27`).

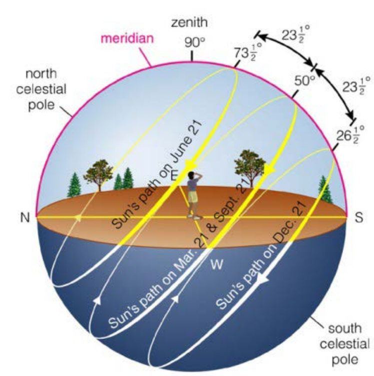


For an observer between the Tropics in the Torrid Zone: (Latitude < 23° 27` N or S):

- The Sun rises and sets every day. (Dec. of Sun + Latitude < 90°)
- Twice a year the declination of the Sun will definitely be equal to the latitude of any observer in the Torrid Zone and on such days the Sun will pass through the zenith of the observer at noon.
- The Sun crosses the prime vertical circle above the horizon when (Declination < latitude; same names).



For an observer in the Temperate zone (23° 27` < Lat. < 66° 33` N or S:



- The Sun is never in the zenith because we always have : (Dec. of Sun < Lat.).
- The Sun definitely rises and sets since (Dec. of Sun + Lat. < 90°).

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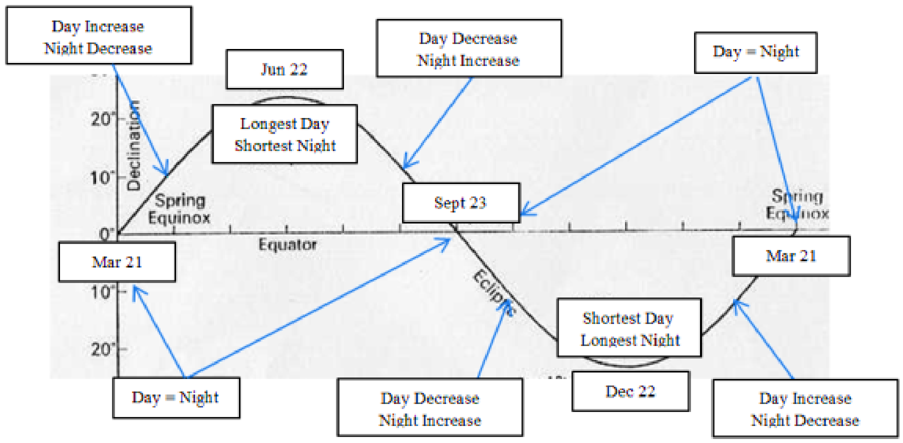
North Latitude Observer



Following day and night phenomena for a North Latitude observer < 66°.5

1. At Vernal Equinox 21st March, day ≈ night.
2. Following to 21st March, day increase and night decrease.
3. At Summer Solstice 22nd June, longest day and shortest night occurs.
4. Following to 22nd June, day decrease and night increase.
5. At Autumnal Equinox 23rd September, day ≈ night.
6. Following to 23rd Sept., day decrease and night increase.
7. At Winter Solstice 22nd Dec., shortest day and longest night occurs.
8. Following to 22nd Dec., day increase and night decrease.
9. At next Vernal Equinox 21st March, day ≈ night, and the sequence is repeated.

Example:
Alexandria / Egypt Lat. ≈ 30° N

1st day	Sunrise	Sunset	Day light
21st Mar. day light = 12h 07m			
Apr.	5h 50m	18h 18m	12h 28m
May	5h 18m	18h 36m	13h 18m
June	4h 59m	18h 56m	13h 57m
22nd June day light = 14h 05m			
Jul.	5h 02m	19h 05m	14h 03m
Aug.	5h 18m	18h 55m	13h 37m
Sept.	5h 36m	18h 24m	12h 48m
23rd Sept. day light = 12h 09m			
Oct.	5h 52m	17h 47m	11h 55m
Nov.	6h 13m	17h 14m	11h 01m
Dec.	6h 37m	17h 00m	10h 23m
22nd Dec day light = 10h 13m			
Jan.	6h 56m	17h 11m	10h 15m
Feb.	6h 51m	17h 36m	10h 45m
Mar.	6h 27m	17h 58m	11h 31m

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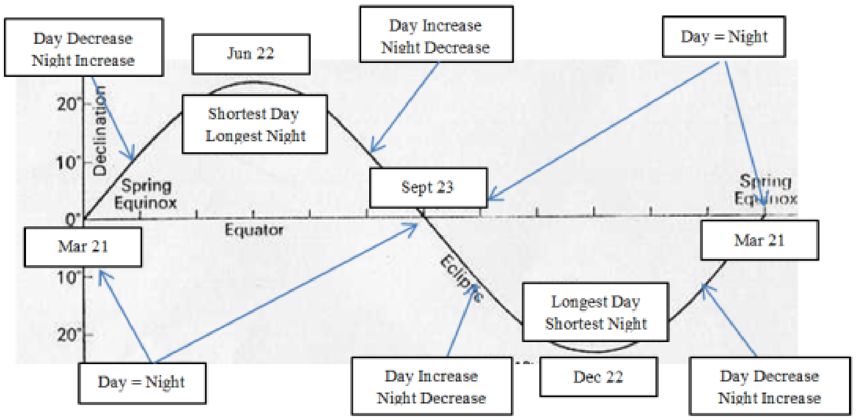
South Latitude Observer



Following day and night phenomena for a South Latitude observer < 66°.5

1. At Vernal Equinox 21st March, day ≈ night.
2. Following to 21st March, day decrease and night increase.
3. At Summer Solstice 22nd June, shortest day and longest night occurs.
4. Following to 22nd June, day increase and night decrease.
5. At Autumnal Equinox 23rd September, day ≈ night.
6. Following to 23rd Sept., day increase and night decrease.
7. At Winter Solstice 22nd Dec., longest day and shortest night occurs.
8. Following to 22nd Dec., day decrease and night increase.
9. At next Vernal Equinox 21st March, day ≈ night, and the sequence is repeated.

Example:
Sidney/ Australia Lat. ≈ 34° S

1st day	Sunrise	Sunset	Day light
21st Mar. day light = 12h 09m			
Apr.	6h 06m	17h 52m	11h 46m
May	6h 29m	17h 16m	10h 47m
June	6h 51m	16h 55m	10h 04m
22nd June day light = 9h 54m			
Jul.	7h 01m	16h 57m	9h 56m
Aug.	6h 48m	17h 15m	10h 27m
Sept.	6h 14m	17h 37m	11h 23m
23rd Sept. day light = 12h 07m			
Oct.	5h 33m	17h 57m	12h 24m
Nov.	4h 55m	18h 22m	13h 27m
Dec.	4h 37m	18h 51m	14h 14m
22nd Dec day light = 14h 24m			
Jan.	4h 48m	19h 10m	14h 22m
Feb.	5h 16m	19h 01m	13h 45m
Mar.	5h 42m	18h 33m	12h 51m

For an observer in the polar zone
(Lat. > 66° 33′ N or S):

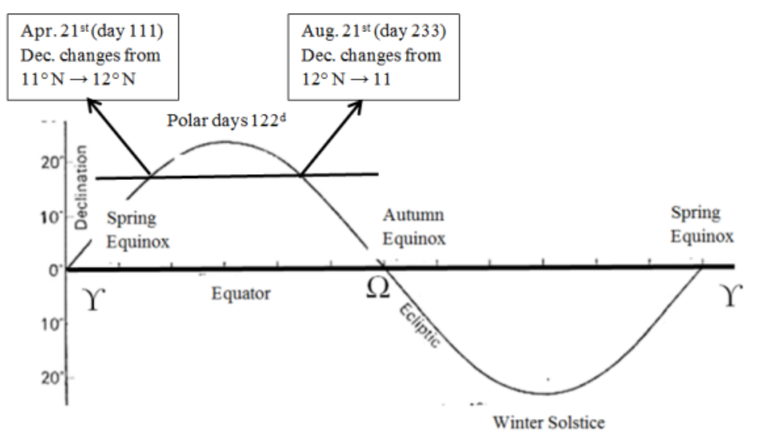
- One may observe a non-setting or non-rising Sun, since in these latitudes the condition:
  Dec. of Sun + Lat. > 90 ° is fulfilled.

- The number of days with non-setting Sun (***polar days***) or non-rising Sun (***polar nights***) increases with increasing the latitude of the observer. (See table).

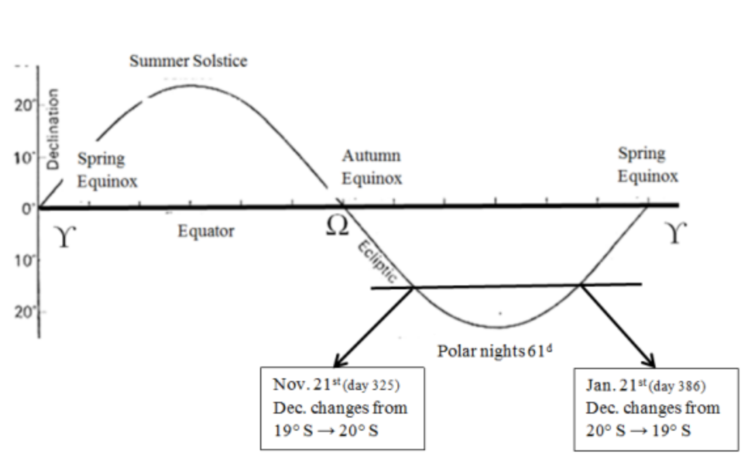
Relation between Latitude and number of polar days

Latitude	Polar days begins	Polar days ends	Polar days
67° N	June 10th	July 3rd	23d
68° N	June 1st	July 12th	41d
69° N	May 25th	July 18th	54d
70° N	May 20th	July 23rd	61d
71° N	May 16th	July 28th	73d

Observer in Arctic Zone Green Harbor Latitude 78° N



Observer in Arctic Zone Port Vadso Latitude 70° N



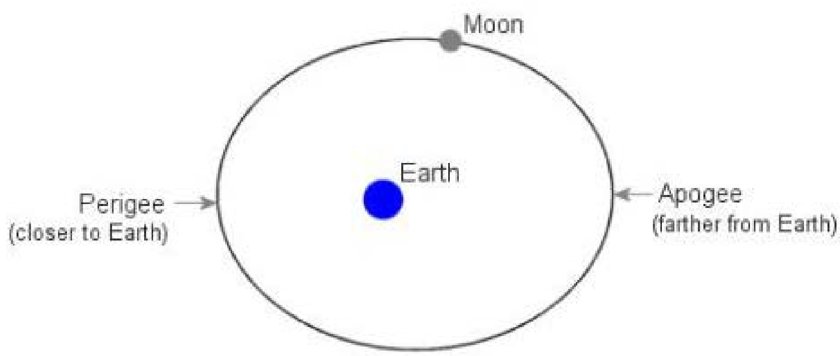
Following day & night phenomena for an observer in Latitude ≈70° N starting from Vernal Equinox To Autumnal Equinox

Day	Sunrise	Sunset	Day time
21st Mar	5h 58m	18h 17m	12h 19m
Apr. 1st	5h 06m	19h 02m	13h 56m
May 1st	2h 34m	21h 20m	18h 46m
May 10th	1h 35m	22h 17m	20h 42m
May 15th	0h 47m	23h 06m	22h 19m
May 16th	0h 31m	23h 22m	22h 51m
≈ *May 20th Polar days begins*			
≈ July 23rd *Polar days ends*			
Jul. 29th	0h 38m	23h 35m	22h 57m
Jul. 30th	0h 55m	23h 18m	22h 23m
Jul. 31st	1h 07m	23h 05m	21h 58m
Aug. 1st	1h 18m	22h 55m	21h 37m
Aug. 5th	1h 51m	22h 21m	20h 30m
Aug. 10th	2h 24m	21h 47m	19h 23m
Aug. 15th	2h 52m	21h 18m	18h 26m
Aug. 20th	3h 17m	20h 51m	17h 34m
Aug. 25th	3h 40m	20h 25m	16h 45m
Aug. 30th	4h 02m	20h 00m	15h 58m
Sept. 1st	4h 11m	19h 50m	15h 39m
Sept. 5th	4h 28m	19h 30m	15h 02m
Sept. 10th	4h 48m	19h 06m	14h 18m
Sept. 15th	5h 08m	18h 43m	13h 35m
Sept. 20th	5h 28m	18h 19m	12h 51m
Sept.23rd	5h 40m	18h 06m	12h 26m
Sept. 25th	5h 47m	17h 56m	12h 09m
Sept. 30th	6h 07m	17h 33m	11h 26m

Apparent Motion
Of the Moon

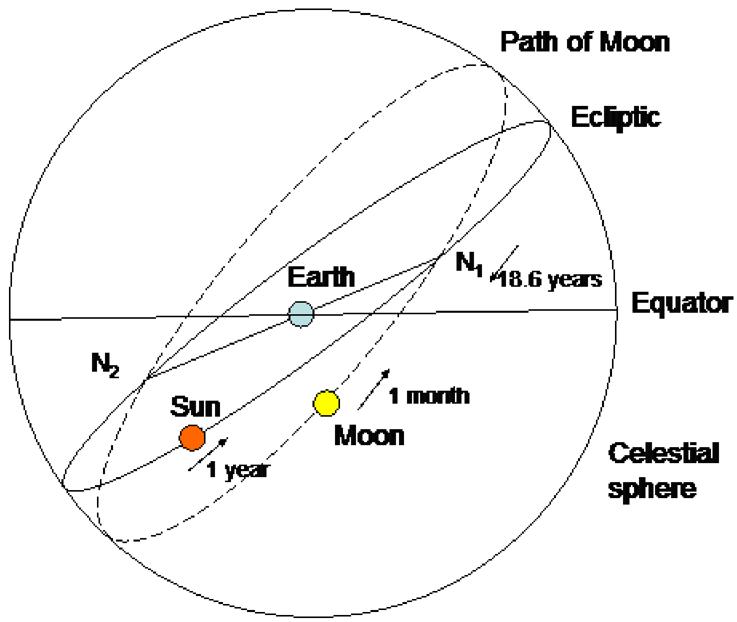
The Moon's orbit:

1. Like any other heavenly satellite, the moon obeys Kepler's laws, and rotates around the earth in an elliptical orbit which in this case is very nearly circular, mean eccentricity of 0.0549.
2. The Mean radius of its orbit is ***385000 Km*** from the center of the earth.



3. The mean angular daily movement relative to an imaginary observer at the barycenter is 13°.176 to the east.
4. When the moon reaches its nearest position to the earth it is said to be *in Perigee* (≈ 362600Km), and when farthest away it is said to be *in Apogee* (≈ 405400 Km).

5. The plane of the moon's orbit is inclined to the ecliptic at an angle of about (5° 09`) and the projection of this orbit on the celestial sphere is nearly a great circle cutting the ecliptic in two opposite points called *nodes.* The *ascending node* is where the moon's path crosses the ecliptic moving from south to north whilst the other is the *descending node.*
6. These nodes are not fixed but move westwards or retrograde along the ecliptic completing a full circuit in 18.6 years or 19°.3549 per year.



PHENOMENAS RELATED TO MOON`S ORBIT

There are four phenomena in direct relation to the Moon`s orbit; they are:

- Size of the Moon
- Lunar periods
- Phases of the Moon
- One side only can be seen

These four phenomena are discussed in the followingparts.

A. Size of the Moon:

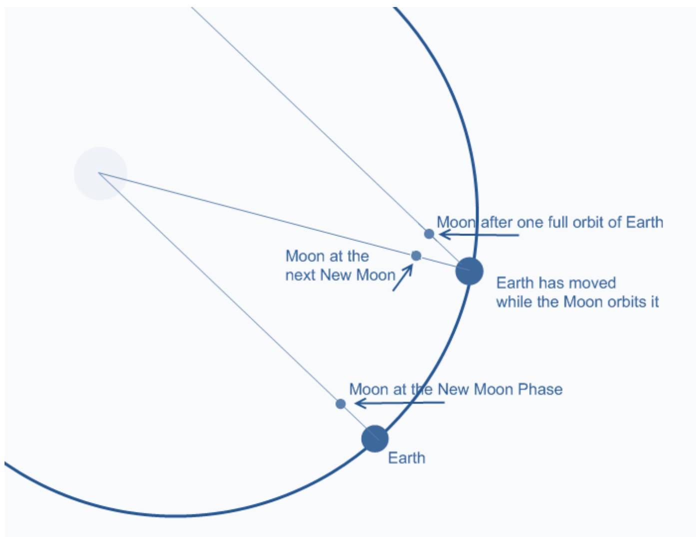
At lunar perigee the apparent angular radius of the Moon`s disc is maximum, while at lunar apogee it will be minimum. The apparent angular radius ranges from 14`.65 to 17`.05. This means that the apparent disc will be smaller by about 14% when in apogee than perigee situation.

The Super Moon was a full Moon that occurred when the Moon was closest to Earth in its elliptical orbit.

Similarly the Mini Moon was a full Moon that occurred when the Moon was farthest from Earth in its elliptical orbit. The phenomena of SUPER MOON were happened at perigee of 2011-03-19; whilst the phenomena of MINI MOON were happened at Apogee of 2011-10-13.

B. Lunar periods

There are several ways to measure how much time it takes the Moon to complete one orbit.
The *sidereal month* is the time it takes to make one complete orbit with respect to the fixed stars, which is about 27.3 days.
In contrast, the *synodic month* is the time it takes the Moon to reach the same phase, which takes about 29.5 days. The *synodic period* is longer than the sidereal period because the Earth–Moon system moves a finite distance in its orbit around the Sun during each sidereal month, and a longer time is required to achieve the same relative geometry. Above figure illustrates this phenomena.



Other definitions for the duration of a lunar month include the time it takes to go from perigee to perigee (the *anomalistic month*), from ascending node to ascending node (the *draconic month*), and from two successive passes of the same ecliptic longitude (the *tropical month*). As a result of the slow precession of the lunar orbit, these latter three periods are only slightly different from the sidereal month.

The properties of the orbit described above are approximations. The Moon's orbit around the Earth has many irregularities.

mentioned lunar periods are summarized in the following table:

Table of Lunar Periods		
Name	Value (days)	Definition
sidereal month	27.32166155	with respect to the distant stars .
synodic month	29.53058886	with respect to the Sun.
anomalistic month	27.554550	with respect to the perigee **(processes** in 8.8504 years)
draconic (nodical) month	27.212220815	with respect to the ascending node (**completed** in 18.5996 years)
tropical month	27.321582	With respect to the vernal Equinox point .

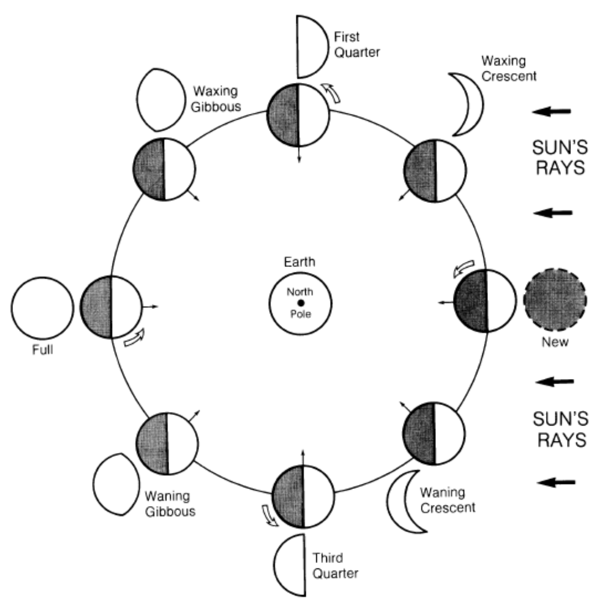
C. Phases of the Moon

It's probably easiest to understand the moon cycle in this order: new moon and full moon, first quarter and third quarter, and the phases in between.

As shown in the above diagram, the **new moon** occurs when the moon is positioned *between* the earth and sun. The three objects are in approximate alignment. The entire illuminated portion of the moon is on the back side of the moon, the half that we cannot see.

At a **full moon**, the earth, moon, and sun are in approximate alignment, just as the new moon, but the moon is on the opposite side of the earth, so the entire sunlit part of the moon is facing us. The shadowed portion is entirely hidden from view.

The **first quarter** and **third quarter** moons (both often called a "**half-moon**"), happen when the moon is at a 90 degree angle with respect to the earth and sun. So we are seeing exactly half of the moon illuminated and half in shadow.



Once you understand those four key moon phases, the phases between should be fairly easy to visualize, as the illuminated portion gradually transitions between them.

An easy way to remember and understand those "between" lunar phase names is by breaking out and defining 4 words: crescent, gibbous, waxing, and waning.

The word *crescent* refers to the phases where the moon is *less* than half illuminated.

The word *gibbous* refers to phases where the moon is *more* than half illuminated.

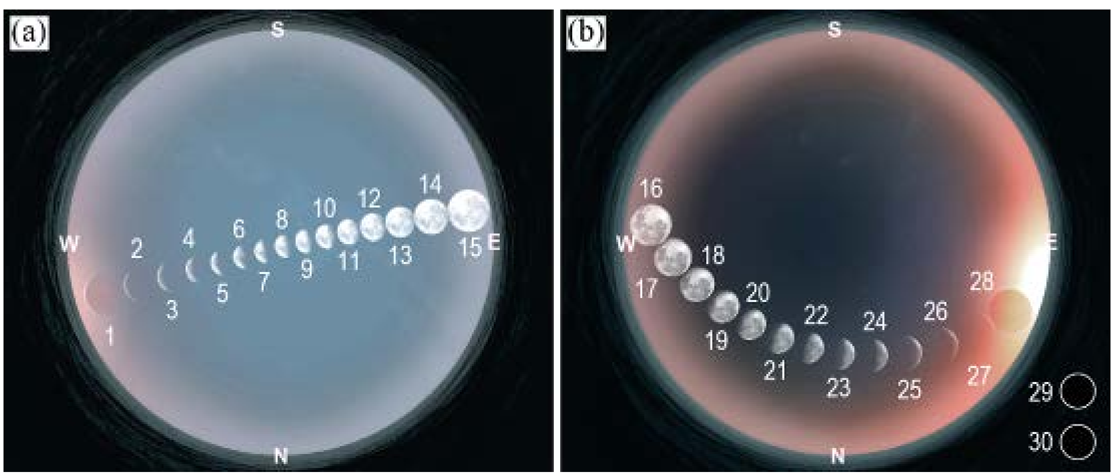
Waxing essentially means "growing" or expanding in illumination, and *waning* means "shrinking" or decreasing in illumination.

Thus you can simply combine the two words to create the phase name, as follows:

After the new moon, the sunlit portion is increasing, but less than half, so it is **waxing crescent**. After the first quarter, the sunlit portion is still increasing, but now it is *more* than half, so it is **waxing gibbous**. After the full moon (maximum illumination), the light continually decreases. So the **waning gibbous** phase occurs next. Following the third quarter is the **waning crescent**, which wanes until the light is completely gone -- a new moon.

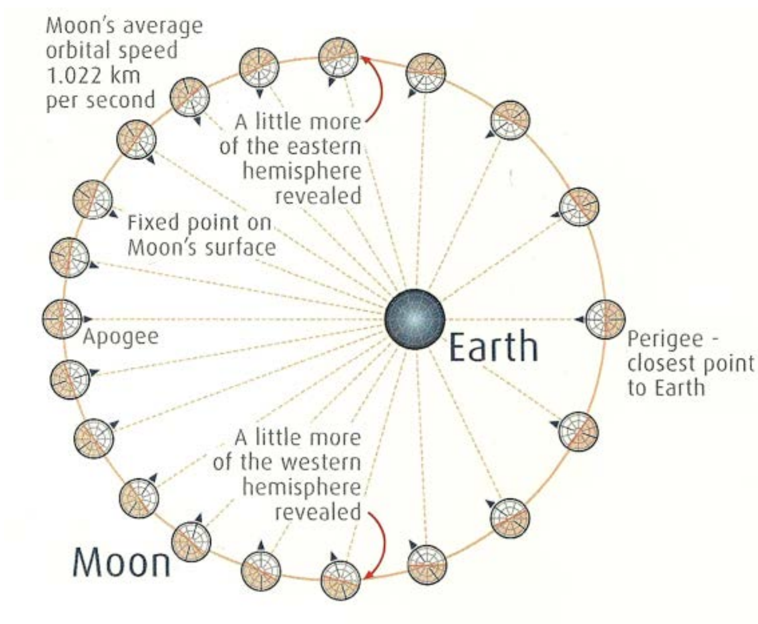
phase	Ahead or Behind the Sun	Rise Time in East	Mid-Point In Sky	Set Time In West
New	Within few minutes	*Sunrise*	*Noon*	*Sunset*
1st Qtr.	6 h behind	*Noon*	*Sunset*	*Midnight*
Full	12 h behind	*Sunset*	*Midnight*	*Sunrise*
3rd Qtr.	6 h ahead	*Midnight*	*Sunrise*	*Noon*

Times of Moonrise; reaching mid-point (meridian) and Moonset for each phase; with respect to Sunrise, Noon, Sunset and midnight times are summarized in the following table:



D. Why one side only?

The Moon is always has the same side pointing towards the Earth due to its rotating speed matching its orbit around the Earth exactly. This is clear from the figure shown.



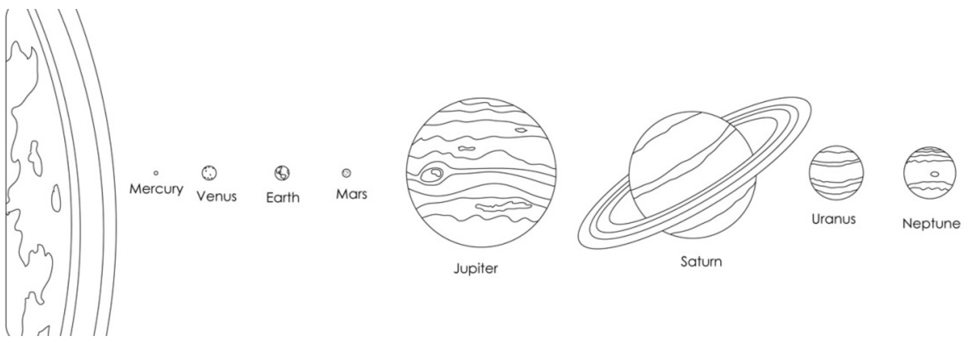
It moves eastward in its orbit as viewed from Earth, about 13 degrees per day (changing rise/set times by ~50 minutes/day).

Apparent Motion of Planets

NEW SOLAR SYSTEM

The new solar system consists mainly of 8 planets, and 5 dwarf planets. In order of their distance from the sun, they are:

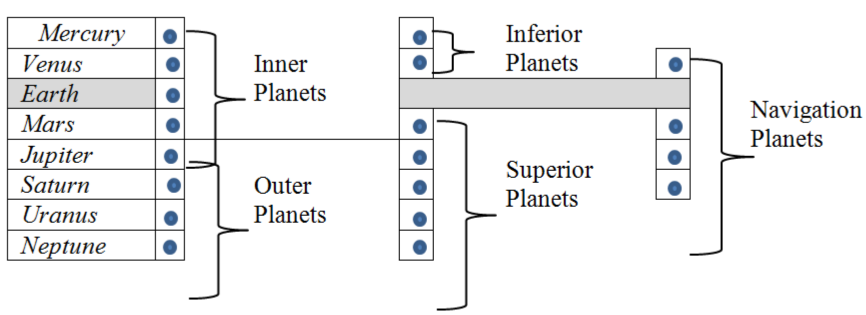
1. *Mercury*
2. *Venus*
3. *Earth*
4. *Mars*
5. *Jupiter*
6. *Saturn*
7. *Uranus*
8. *Neptune*



The planets are classified into:

- *Inner and Outer Planets*
  This classification is due to their similarity in compositions.
- *Inferior and Superior Planets*
  This classification is due to their orbits regarding that of the earth.
- *Navigational and Non-Navigational Planets.*
  These classifications in accordance to their visibility in the night sky.

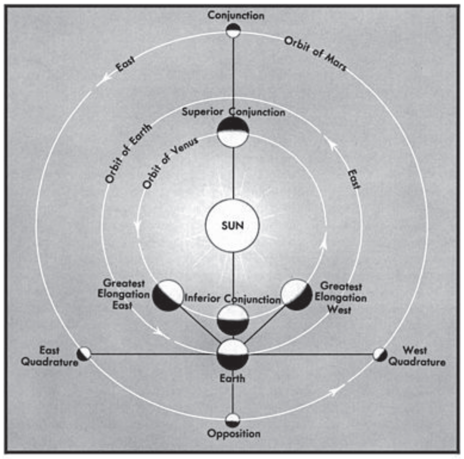
These classifications are shown in the following diagram.



Relative Positions of Planets:

A. Inferior Planets:

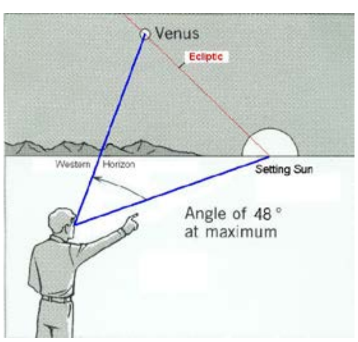
Mercury and Venus are inferior planets in the Solar System. They are closer to the Sun than the Earth. Mars, Jupiter, Saturn, Uranus and Neptune are superior planets in the Solar System. They are further away from the Sun than the Earth.

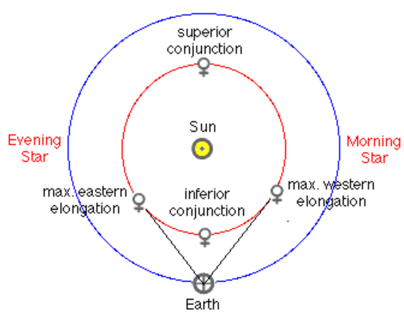


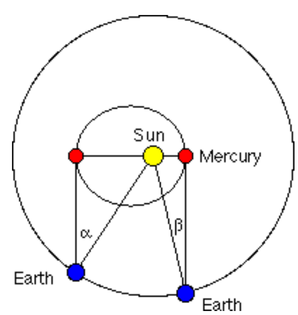
From the Earth's perspective, the angular distance between the Sun and a planet is the *Elongation*. An elongation of 0° is called conjunction, one of 90° is quadrature, and one of 180° is opposition.

For an inferior planet, the conjunction is called inferior conjunction if the planet is between the Sun and the Earth, and is called superior conjunction if it is on the opposite side of the Sun from the Earth.

When an inferior planet follows the Sun and appears east of the Sun in the evening, it is in eastern elongation. When an inferior planet precedes the Sun and appears west of the Sun in the morning, it is in western elongation.





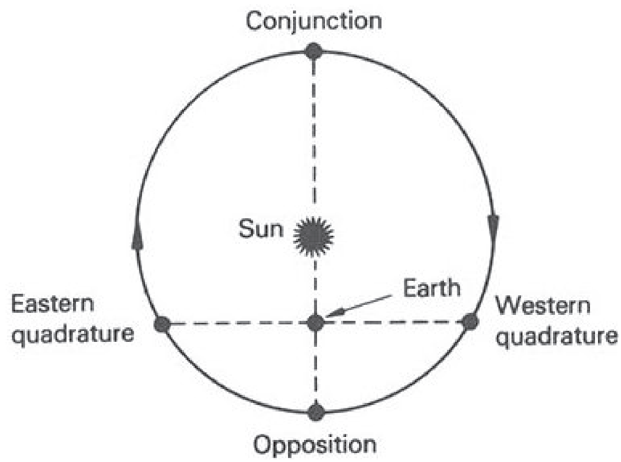


As both the orbits of an inferior planet and the Earth are elliptical rather than circular, the greatest elongation varies from 18° to 28° for Mercury and 47° to 48° for Venus respectively.

B. Superior Planets

A superior planet at opposition is closest to the Earth and appears the brightest. See the following Table.

At conjunction, a superior planet will be invisible due to the Sun's glare.



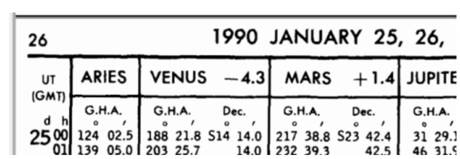
The following table gives the dates and magnitudes of *OPPOSITION,* for the navigational superior planets, in the years 2015 -2020.

year	MARS		JUPITER		SATURN	
	Date	Mag.	Date	Mag.	Date	Mag.
2015			06-Feb	-2.57	23-May	0.02
2016	22-May	-2.06	08-Mar	-2.49	03- Jun	0.00
2017			07- Apr	-2.46	15-Jun	0.00
2018	27-Jul	-2.78	09- May	-2.51	27-Jun	0.02
2019			10-Jun	-2.61	09-Jul	0.05
2020	13-Oct	-2.62	14-Jul	-2.75	20-Jul	0.10

Australian Amateur Astronomy

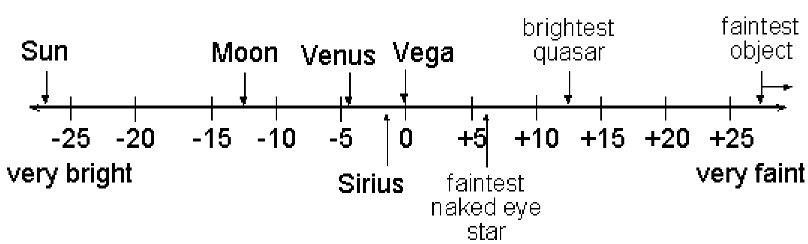
Magnitude of Planets:

The data of the 4-navigational planets are tabulated in the left-hand page of the *Nautical Almanac Tables*. The head of each column contains the apparent magnitude of each planet. In the figure shown for January 25,26,27 1990, the apparent magnitude of planet Venus is -4.3 and that of Mars is +1.4.


26 1990 JANUARY 25, 26,

UT (GMT)	ARIES	VENUS −4.3		MARS +1.4		JUPITE
d h	G.H.A.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.
25 00	124 02.5	188 21.8	S14 14.0	217 38.8	S23 42.4	31 29.1
01	139 05.0	203 25.7	14.0	232 39.3	42.5	46 31.9

From the following scale of the magnitude system, Venus is the brightest object following to Sun and Moon.



Apparent brightnesses of some objects in the magnitude system.

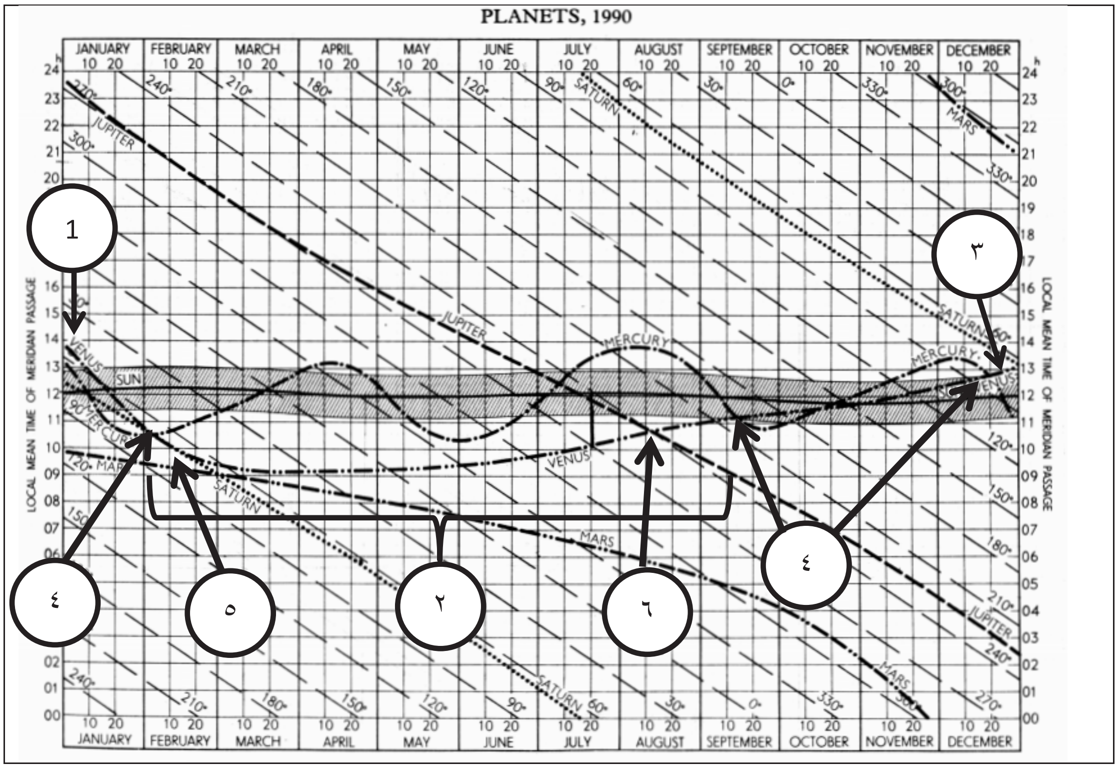
*Planet Diagr*am

In the Nautical Almanac Tables page (9) a *Planet Diagr*am is printed. In our stage of study we give importance to:

a) Whether a planet is too close to the sun for observation;
b) Some indication of its position in the sky, especially during twilight;
c) The proximity of other planets.

An Example of planet Venus is given through the *Planet Diagram* of the year 1990.

Planet Diagram of the year 1990.



VENUS

1) Venus is a brilliant object in the evening sky for the first few days of the year when it becomes too close to the Sun for observations.
2) Towards the end of January it reappears as a morning star and can be seen until a few days after mid-September when it again becomes too close to the Sun for observations.
3) It reappears in the evening sky in mid-December.
4) Venus is in conjunction with Mercury on February 4, September 14 and December 18.
5) Venus is in conjunction with Saturn on February 7 and 14.
6) Venus is in conjunction with Jupiter on August 12.

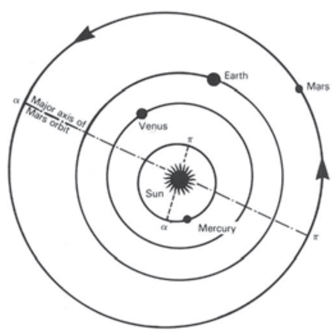
Kepler`s Laws:

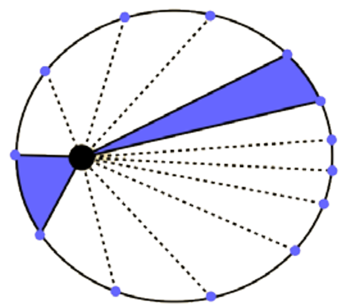
Johannes Kepler, working with data painstakingly collected by **Tycho Brahe** without the aid of a telescope, developed three laws which described the motion of the planets across the sky.

A. The *Law of Orbits.*
B. The *Law of Areas*.
C. *The Law of Periods*.

Kepler's laws were derived for orbits around the sun, but they apply to satellite orbits as well.

The Law of Orbits
All planets move in elliptical orbits, with the sun at one focus.



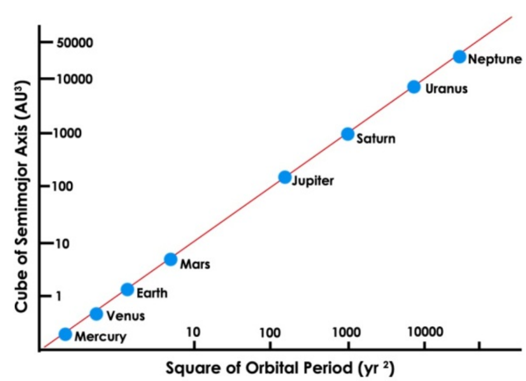


The Law of Areas
A line that connects a planet to the sun sweeps out equal areas in equal times.
Note:
The speed of the planet increases as it nears the sun and decreases as it recedes from the sun. This means that the speed of the planet is no uniform.

The Law of Periods
The square of the period of any planet is proportional to the cube of the semi-major axis of its orbit.
The mathematical form of this law is given as:

$$\frac{(T1)^2.(Ms+M1)}{(T2)^2.(Ms+M2)} = \frac{a1^3}{a2^3};$$

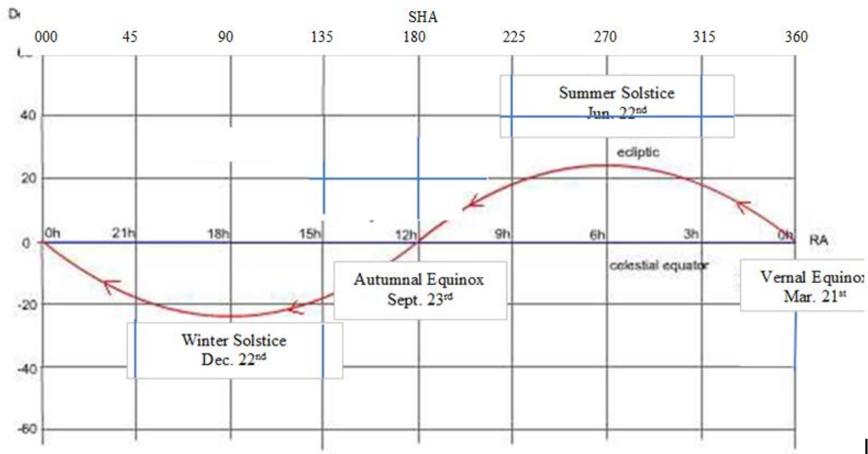
Where
M_1: mass of planet$_1$
M_2: mass of planet$_2$
M_S: mass of the Sun
a_1: semi-major axis of the orbit of planet$_1$
a_2: semi-major axis of the orbit of planet$_2$
T_1: sidereal period of planet$_1$
T_2: sidereal period of planet$_2$

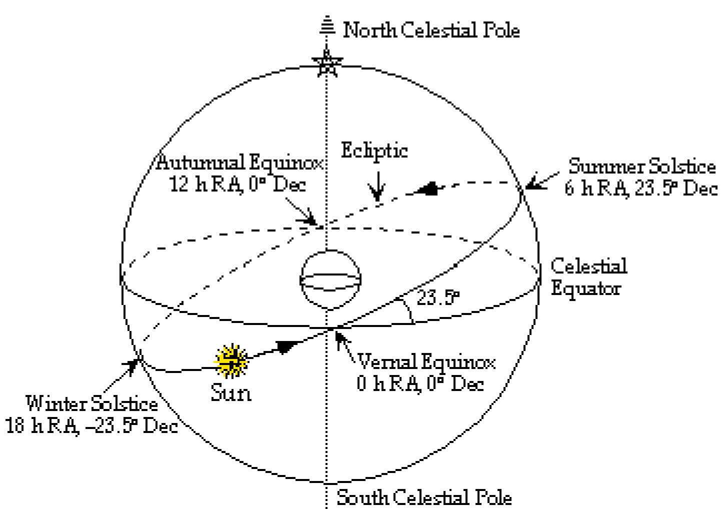


Identification of Navigation Stars

Apparent Annual Path of the Sun among the Stars:

Regarding star maps we notice that the sun moves in a sine curve; half of this curve is situated in the northern hemisphere and the other in the southern hemisphere. This curve is the projection of the annual great circle in which the sun moves among the stars and known as the Ecliptic.





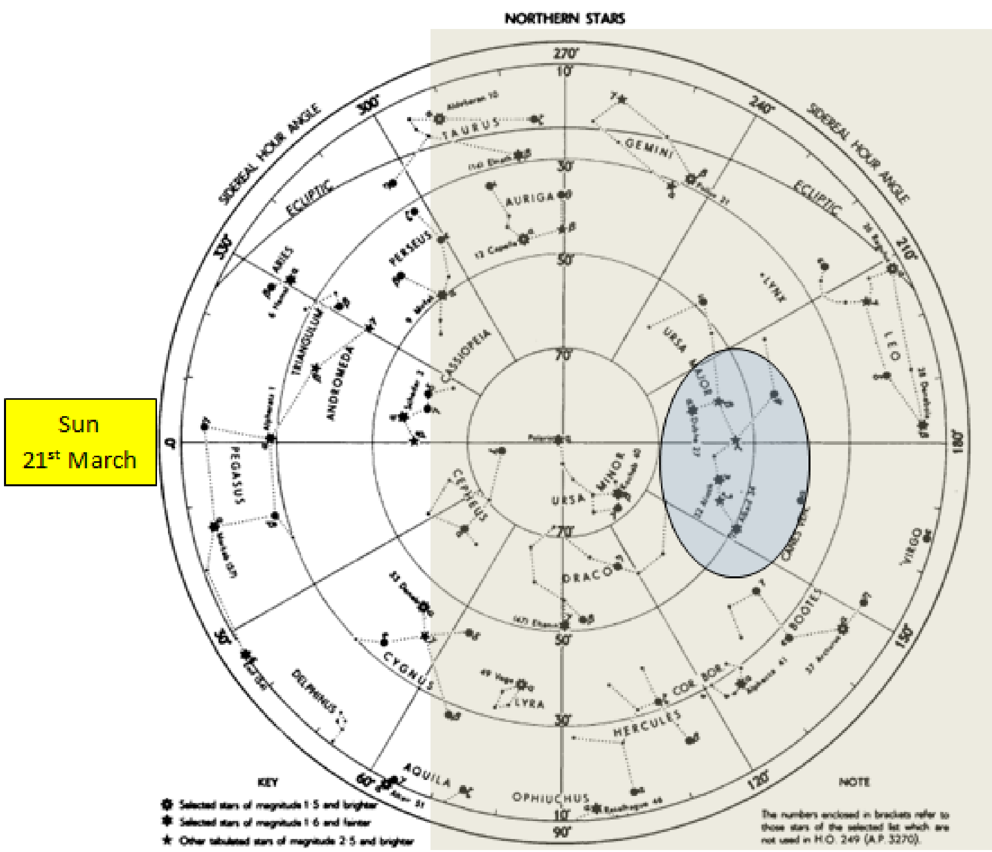
Ecliptic

Appear and Disappear of Stars:

When the sun moves in the Ecliptic; its Right Ascension increase (true motion) and Sidereal Hour Angle decrease (apparent motion). This is the cause of seeing different stars oppositely to the sun`s position. This is explained as follows.

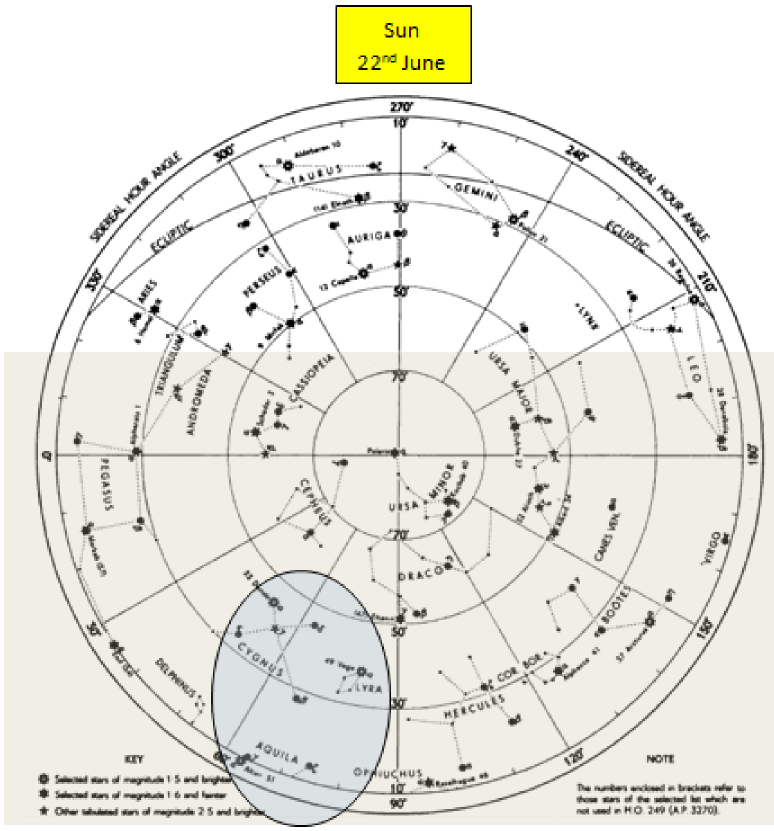
A. Stars of Northern Spring:

Sun reaches SHA= 000° at about (20th – 21st) March. This means that the stars of SHA= 180° are seen in the middle of the celestial sphere at midnight. Regarding map of stars given in the *Nautical Almanac Tables*; we find that the stars of *Ursa Major* and neighbor stars verify this condition. Those are Northern Spring Stars.



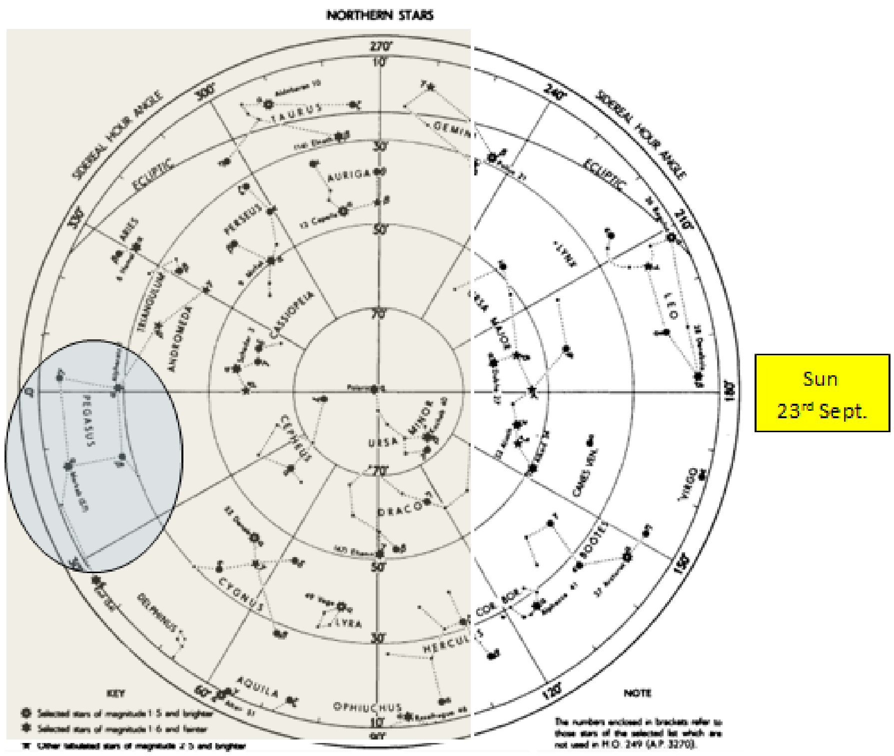
B. Stars of Northern Summer:

Sun reaches SHA= 270° at about (21st – 22nd) June. This means that the stars of SHA= 90° are seen in the middle of the celestial sphere at midnight. Regarding map of stars given in the *Nautical Almanac Tables*; we find that the groups of stars known as the *Summer Triangle* and neighbor stars verify this condition. Those are Northern Summer Stars.



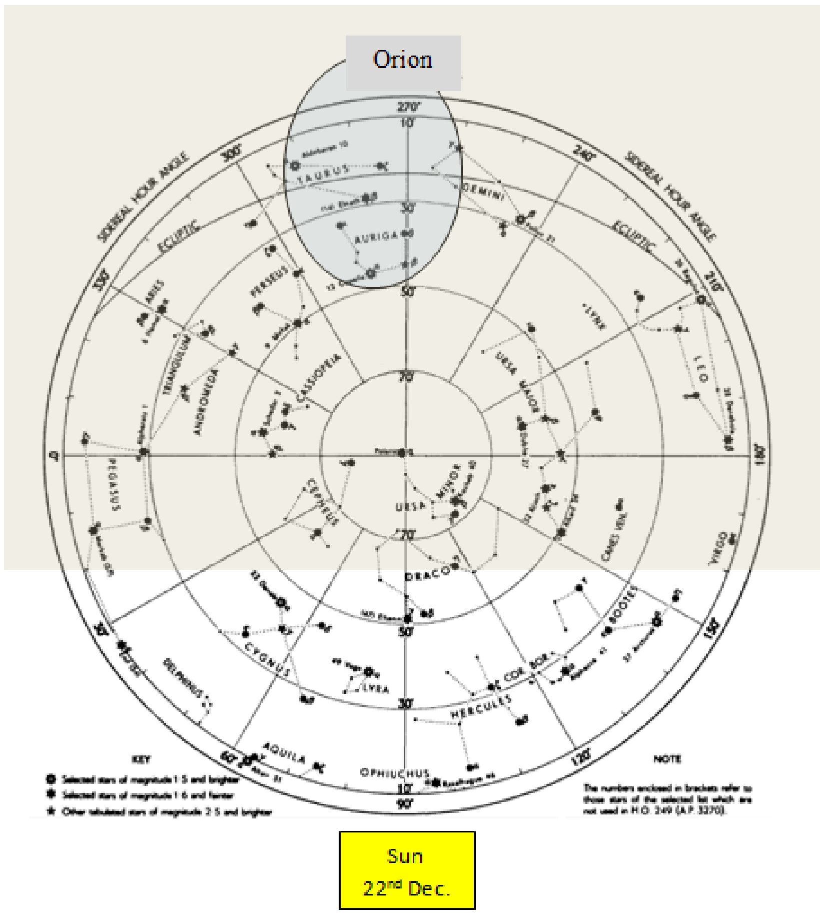
C. Stars of Northern Autumn:

Sun reaches SHA= 180° at about (22nd – 23rd) September. This means that the stars of SHA= 180° are seen in the middle of the celestial sphere at midnight. Regarding map of stars given in the *Nautical Almanac Tables*; we find that the constellation of stars known *Pegasus* and neighbor stars verify this condition. Those are Northern Autumn Stars.



D. Stars of Northern Winter:

Sun reaches SHA= 090° at about (21^{st} – 22^{nd}) December. This means that the stars of SHA= 270° are seen in the middle of the celestial sphere at midnight. Regarding map of stars given in the *Nautical Almanac Tables*; we find that the constellation of stars known *Orion* and neighbor stars verify this condition. Those are Northern Winter Stars.



Coordinates of the Sun and how it affects day and night phenomena is given in the following table. This table is calculated for Alexandria /Egypt (30º N, 30ºE) as an example.

Date	SUN`s Coordinates S.H.A.	SUN`s Coordinates Dec.	Day Interval	Night Interval
Jan.1st	≈ 078º	≈ 23º S	10h 15m 27s	13h 44m 33s
Feb.1st	≈ 045º	≈ 17º S	10h 46m 54s	13h 13m 06s
Mar.1st	≈ 018º	≈ 07º S	11h 33m 01s	12h 26m 59s
March (20th - 21st)	≈ 000º	≈ 00º	12h 07m 26s	11h 52m 34s
	Day equals Night (approximately)			
Apr.1st	≈ 349º	≈ 05º N	12h 29m 13s	11h 30m 47s
May.1st	≈ 321º	≈ 15º N	13h 20m 07s	10h 39m 53s
Jun.1st	≈ 290º	≈ 22º N	13h 57m 07s	10h 02m 53s
June (21st - 22nd)	≈ 270º	≈ 23º.5 N	14h 04m 47s	9h 55m 13s
	Longest day light and shortest night			
Jul.1st	≈ 259º	≈ 23º N	14h 02m 44s	9h 57m 16s
Aug.1st	≈ 228º	≈ 18º N	13h 34m 20s	10h 25m 40s
Sept.1st	≈ 199º	≈ 08º N	12h 45m 36s	11h 14m 24s
Sept. (22nd - 23rd)	≈ 180º	≈ 00º	12h 08m 23s	11h 51m 37s
	Day equals Night (approximately)			
Oct.1st	≈ 172º	≈ 03º S	11h 52m 13s	12h 07m 47s
Nov.1st	≈ 143º	≈ 15º S	10h 59m 10s	13h 00m 50s
Dec.1st	≈ 112º	≈ 22º S	10h 21m 35s	13h 38m 25s
Dec. (21st - 22nd)	≈ 090º	≈ 23º.5 S	10h 12m 54s	13h 47m 06s
	Shortest day light and longest night			
Jan.1st	≈ 078º	≈ 23º S	10h 15m 27s	13h 44m 33s

Introduction:

In the following discussion; we shall apply the simplest way to identify navigational stars. First we recognizes a famous constellation (or set of constellations) from which we can distinguish a lot of neighbor stars.

Applying this method is done as follows:

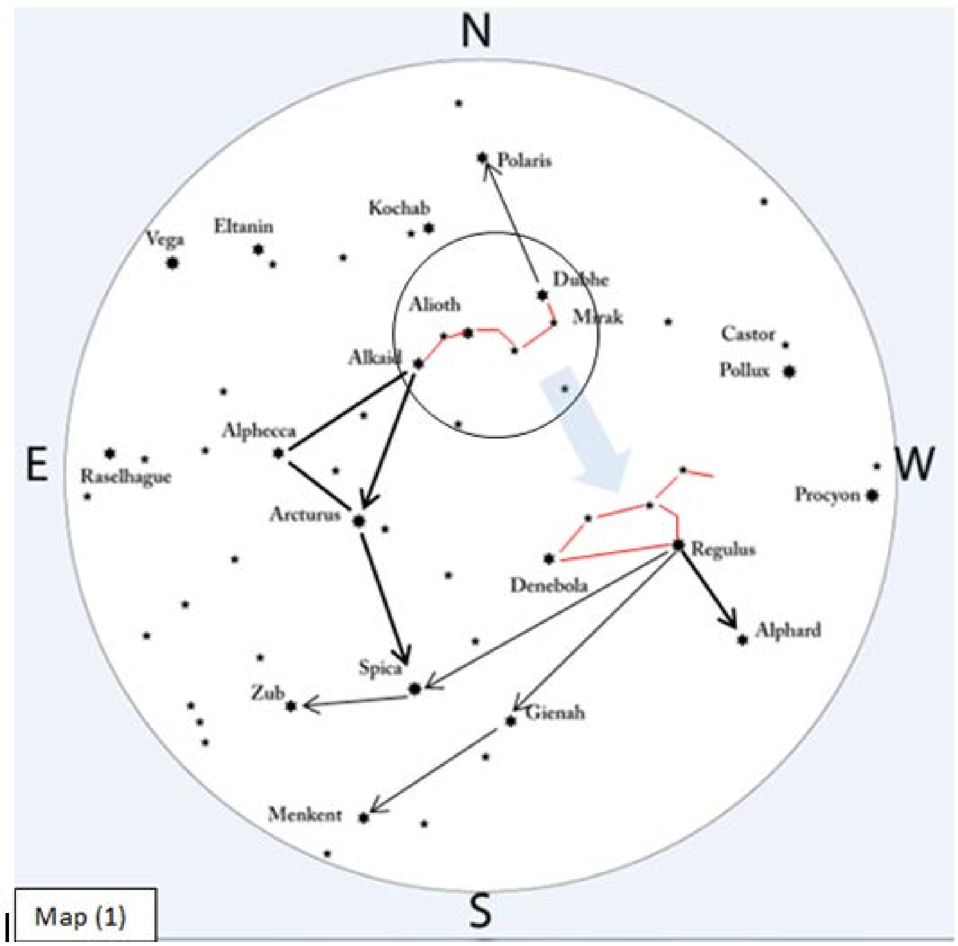
A. For every accompanied map on which names of stars is given; we recognizes the famous basic constellation then reaches every star in the neighborhoods. We obey the following arrangement:
    - Map of northern spring. Midnight of 1st April; where (12) stars are identified.
    - Map of northern summer. Midnight of 1st July; where (11) stars are identified.
    - Map of northern autumn. Midnight of 1st October; where (8) stars are identified.
    - Map of northern winter. Midnight of 1st January; where (12) stars are identified.

    This procedure gives us simplest way to recognize 43 navigation stars regarding the 57 stars named in the daily pages of the *Nautical Almanac Tables.*
B. At the end of discussion the same map used before is given but without names stars to give the student a chance to identify the navigation stars by himself. This needs several trials to be satisfied.
C. A table of times suitable for seeing the same map; is given for every 15 days at the end of discussion.
D. A table of times suitable for seeing the 4 maps; is given at the end of chapter.

Stars of Northern Spring

Basic reference is the Constellation *URSA MAJOR (*Big Dipper)

In the spring, the Big Dipper *(URSA MAJOR)* is above the pole, high in the sky, and serves to point out several excellent navigational stars.



Map (1)

- The above map (1) represents the celestial sphere on April 1st at midnight local time of Alexandria/Egypt ≈ (30° N; 30° E).
- Number of navigation stars recognized are (12) stars.
- The same celestial sphere appears at the following times and dates:

Day/Month	Z.T.
Feb. 1st	0400
Feb. 15th	0300
Mar. 1st	0200

Day/Month	Z.T.
Mar. 15th	0100
Apr. 1st	0000
Apr. 15th	2300

Day/Month	Z.T.
May 1st	2200
May 15th	2100
Jun. 1st	2000

- Ursa Major consists of 7-stars forms a very famous figure; only 3 of them are tabulated in the daily pages of the Nautical Almanac tables as navigation stars. They are ***Dubhe***; ***Alioth*** and ***Alkaid***.

- The outer stars of the bowel ***Dubhe*** and Mirak are known as the pointers because a line from *Mirak* through ***Dubhe*** with 5 folds of distance in between leads to the pole star *Polaris*.

- Starting at the bowel, follow the curvature of the handle. If this curved arc is continued, it leads first to ***Arcturus****,* and then to ***Spica***, both 1st mag. stars much used by the navigator.

- A line northward through the pointers of the big dipper leads to ***Polaris***. If this line is followed in the opposite direction, it leads in the general direction of ***Regulus*** the end of the handle of the sickle (or question mark) in the constellation *Leo* (lion). This much used navigational star is of the 1st mag. and the brightest star in its part of the sky.

- A line connecting ***Regulus*** and ***Arcturus*** passes close to 2nd mag. ***Denebola*** (tail of the lion) sometimes used by navigators.

- ***Alkaid*, *Arcturus*** and ***Alphecca*** form a right angle triangle, right angle at ***Alphecca*.**

- *Corvus* (the crow) resembles more nearly a quadrilateral sail. It is not difficult to find and contains the 3rd mag. navigational star ***Gienah***.

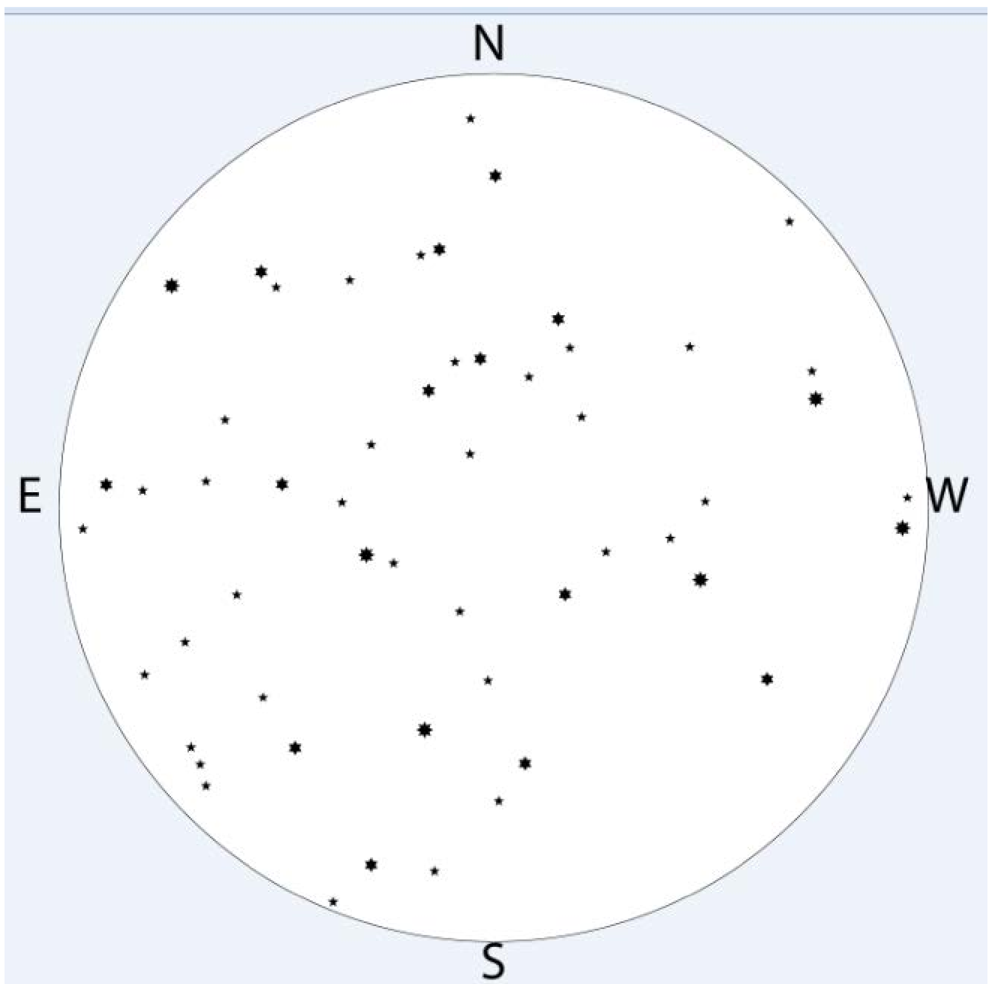
- Starting from ***Regulus***, a line through ***Spica*** in the SE direction leads to a 3rd mag. star ***Zubenelgenubi*,** and from ***Regulus*,** also, a line through ***Gienah*** in the SE direction leads to a 3rd mag. star ***Menkent***.

- The 2nd mag. navigational star ***Alphard*** is more easily identified by its being close to the extension of a line from the pointer of the big dipper through ***Regulus*** and extended southward.

From the discussion above we can identify (12) of navigation stars;

Dubhe, Alioth, Alkaid Arcturus, Spica, Regulus, Denbola, Alphecca, Gienah, Zubenelgenubi,, Menkent, and *Alphard*.

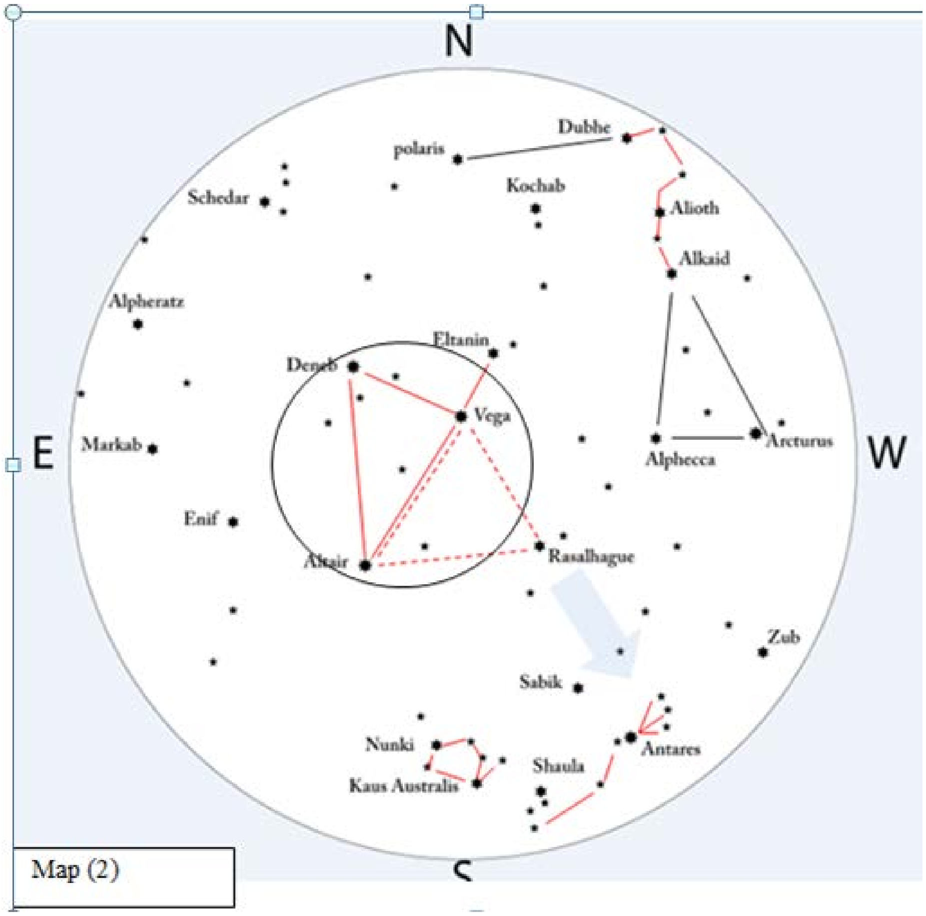
The following map of the spring sky is the same map in next page but without names of the navigation stars. This is to help student to identify and name the navigation stars.



Stars of Northern Summer

Basic reference is a set of Constellations known as *Summer Triangle*

Celestial sphere revolves from East to West according to the apparent diurnal motion; spring stars begins to disappear through the western horizon. The Ursa Major moves to be west of the pole star Polaris. The pointer line seems to be horizontal. Constellation of *Cassiopeia* begins to appear above the eastern horizon.



Map (2)

- The above map (2) represents the celestial sphere on July 1st at midnight local time of Alexandria/Egypt ≈ (30° N; 30° E).
- Number of navigation stars recognized are (9) stars.
- The same celestial sphere appears at the following times and dates:

Day/Month	Z.T.
May 1st	0400
May 15th	0300
Jun. 1st	0200

Day/Month	Z.T.
Jun. 15th	0100
Jul. 1st	0000
Jul. 15th	2300

Day/Month	Z.T.
Aug. 1st	2200
Aug. 15th	2100
Sept. 1st	2000

- The 1st magnitude stars, ***Vega***, ***Deneb*** and ***Altair*** form a distinct right triangle (right angle at ***Vega***), which used as an identification feature. However, each one is in a different constellation which should enable one to identify it without reference to any other stars.

- ***Deneb*** is in the northern cross (*Cygnus*) ; the eastern arm of the cross points to ***Enif***, the western arm to ***Eltanin***, and the bisectors of the lower right angles point to ***Altair*** and ***Vega***.

- ***Altair*** is readily identified by the small stars on either side of it, sometimes called the guardians. It should be kept in mind, however, that the southern guardian is only a 4th magnitude star and may not show too plainly on very hazy or bright moonlight nights. This configuration is unique and should identify ***Altair*** through a break in the overcast with no other stars showing.

- ***Vega*** may be identified under these conditions by an almost perfect parallelogram slightly to the south and east of it. Again, however, these are 4th magnitude stars and are not too distinct if conditions unfavorable.
- ***Rasalhague*** forms nearly an equilateral triangle with ***Vega*** and ***Altair***. This 2nd magnitude star and 3rd magnitude ***Sabik***, to the south, are occasionally used by navigators.

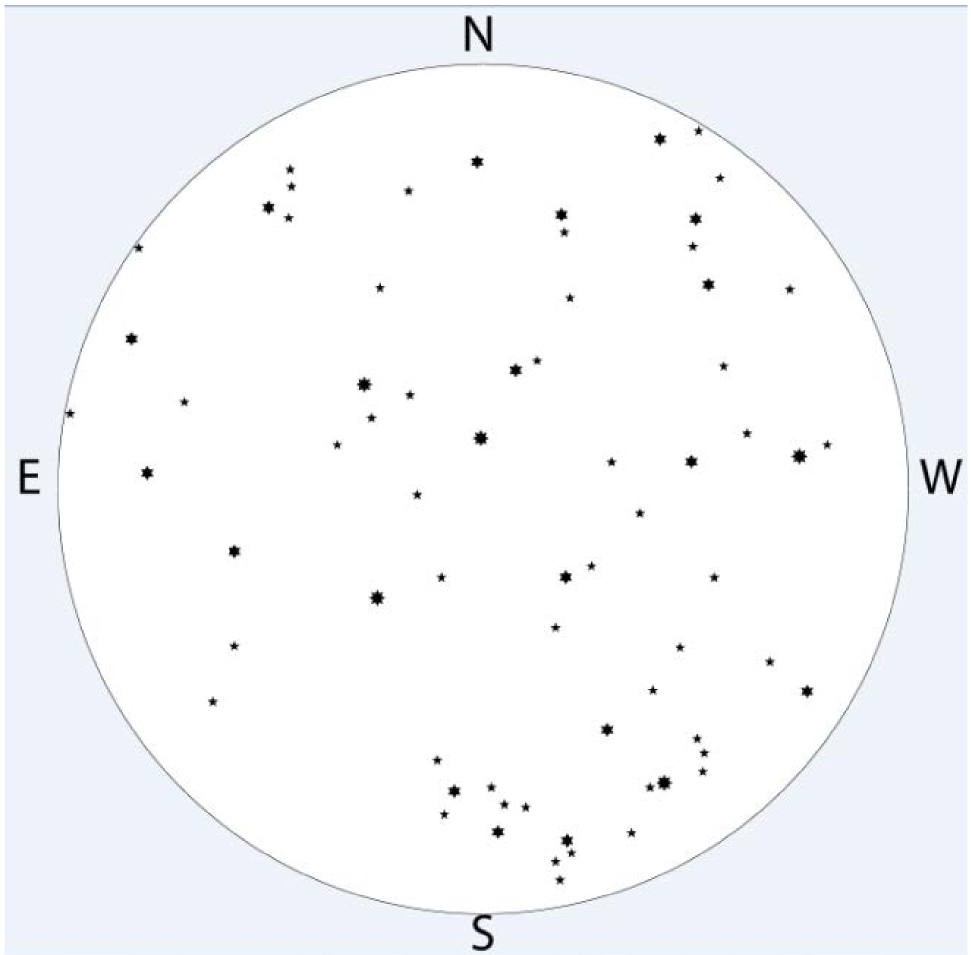
- *Scorpio* (the scorpion) is one constellation which resembles the animal for which it is named without too much stretch of the imagination. The curve from ***Antares***, the main navigational star, to ***Shaula*** is particularly suggestive of a scorpion`s tail.

- Immediately to the east is a group forming the shape of a teapot with the 2nd magnitude star ***Nunki*** in the handle. At the opposite side of the teapot, is the 2nd magnitude star ***Kaus Australis***

From the discussion above we can identify (11) of navigation stars;

Vega, Deneb, Altair, Enif, Eltanin, Rasalhague, Sabik, Antares, Shaula, Nunki and Kaus Australis

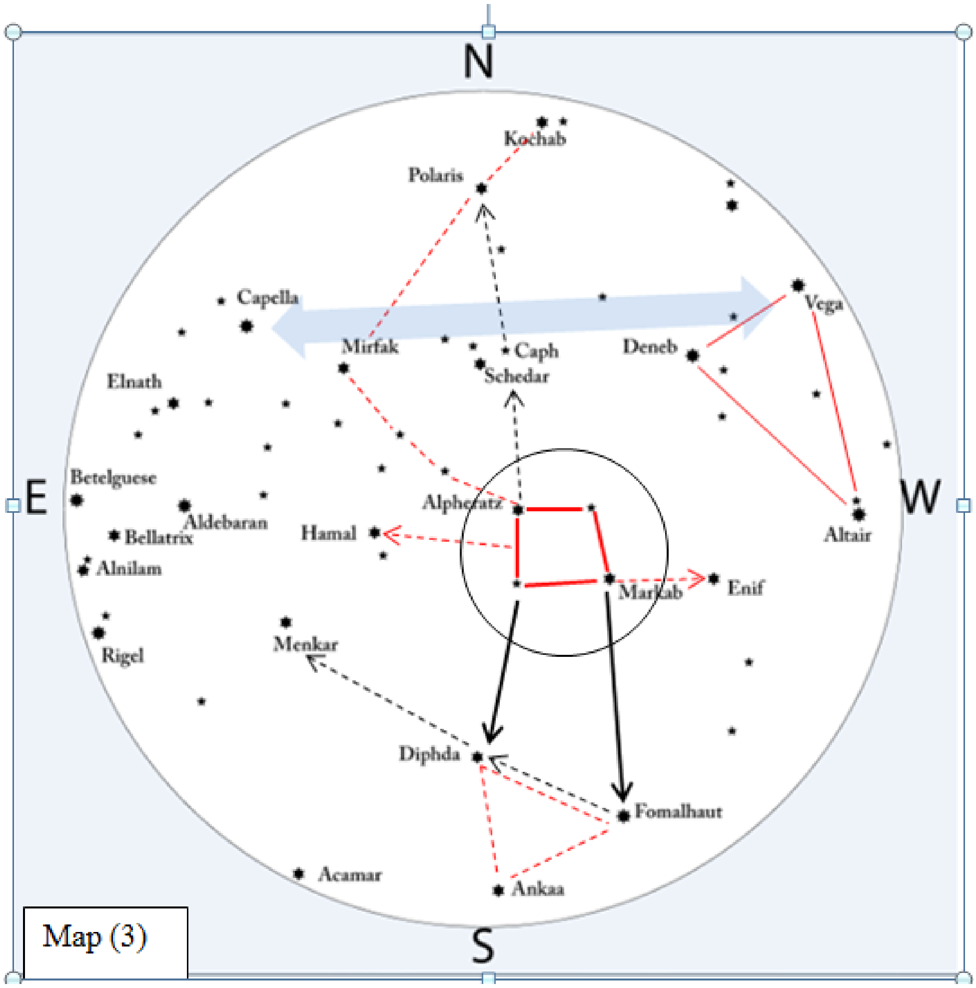
The following map of the spring sky is the same map in the next page but without names of the navigation stars. This is to help student to identify and name the navigation stars.



Stars of Northern Autumn

Basic reference is the Constellation *Pegasus* (winged horse)

The autumn sky is marked by an absence of 1st magnitude stars. The *Northern Cross* has moved to a position low in the western sky, and *Cassiopeia* is nearly on the meridian to the north.



Map (3)

- The above map (3) represents the celestial sphere on October 1st at midnight local time of Alexandria/Egypt ≈ (30° N; 30° E).
- Number of navigation stars recognized are (8) stars.
- The same celestial sphere appears at the following times and dates:

Day/Month	Z.T.
Jul. 15th	0500
Aug. 1st	0400
Aug. 15th	0300
Sept. 1st	0200

Day/Month	Z.T.
Sept. 15th	0100
Oct. 1st	0000
Oct. 15th	2300
Nov. 1st	2200

Day/Month	Z.T.
Nov. 15th	2100
Dec. 1st	2000
Dec. 15th	1900

- For most observers in the Mediterranean, the great square of *Pegasus* (the winged horse) appears nearly on the meridian at zenith. The eastern side of this square, and ***Caph*** in *Cassiopeia,* nearly mark the hour angle of the vernal equinox γ. ***Alpheratz*** and ***Markab***, 2nd magnitude stars at opposite corners of the square, are the principal navigational stars of this constellation. 2nd magnitude ***Enif*** is occasionally used.

- The great square of *Pegasus* is useful in locating several navigational stars. The line joining the stars of the eastern side of the square, if continued southward, leads close to 2nd magnitude ***Diphda*** in Cetus (the sea monster). Similarly, a line joining the stars of the western side of the square, if continued southward, leads close to 1st magnitude ***Foamalhaut***. A line through the center of the square, if continued eastward, leads to 2nd magnitude ***Hamal***, in *Aries* (the ram).

- This was the location of the vernal equinox some 2000 years ago, when it is designated the "the first point of Aries".

- A curved line from ***Markab*** through ***Alpheratz*** leads to the 2nd magnitude ***Mirfak***.

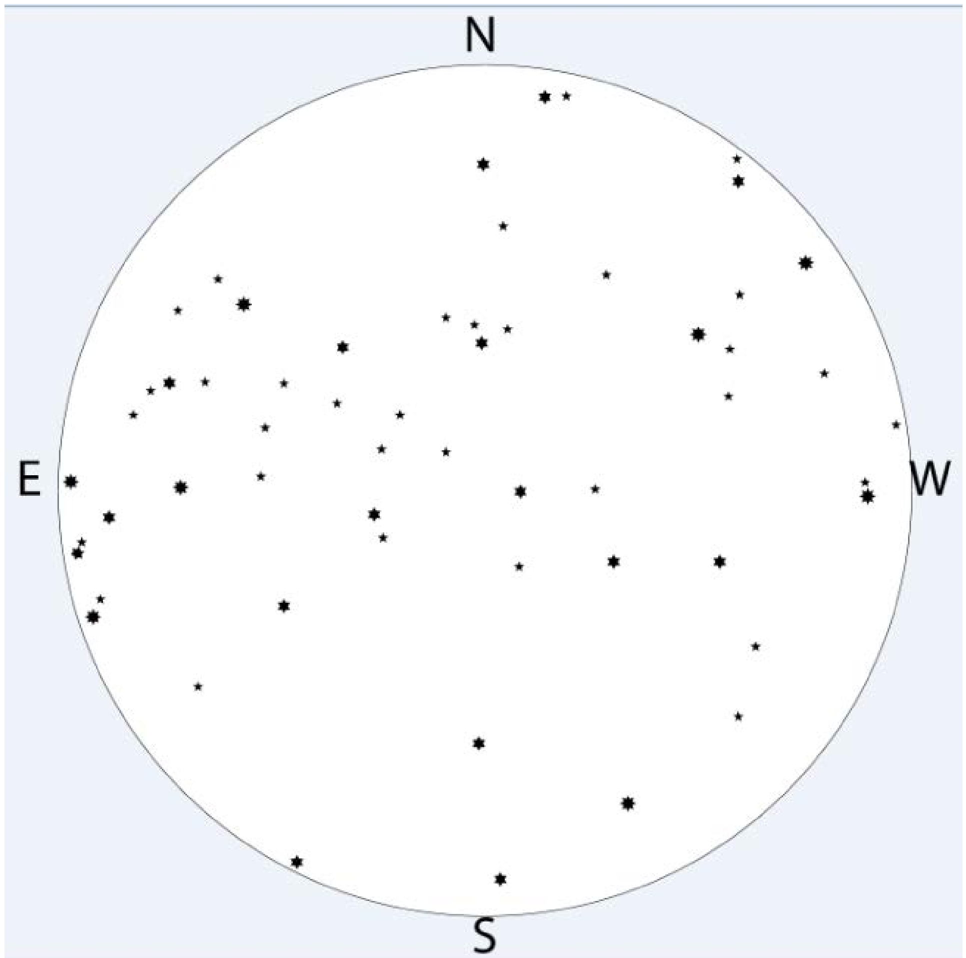
- A line from ***Fomalhaut*** through ***Diphda*** extends about 40° leads to ***Menkar*** knowing that, any side of the square is only 15°.

- ***Famalhaut, Diphda*** and the 2nd magnitude ***Ankaa*** form an equilateral triangle of about 20°.

The navigational stars associated with Pegasus are (8) stars.

Alpheratz, *Markab, Diphda, Fomalhaut, Hamal, Mirfak, Menkar and Ankaa.*

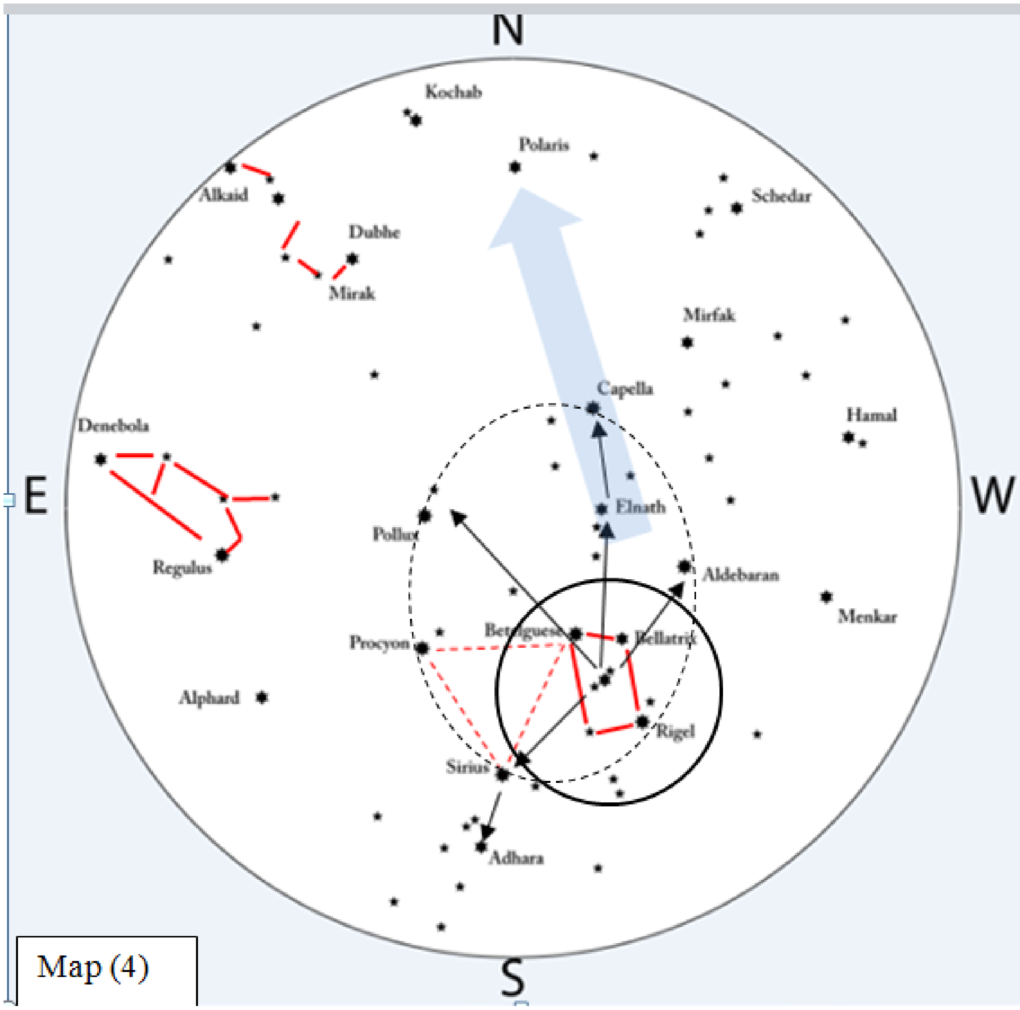
The following map of the spring sky is the same map in the next page but without names of the navigation stars. This is to help student to identify and name the navigation stars.



Stars of Northern Winter

Basic reference is the Constellation *Orion* (the hunter)

No other part of the sky contains so many bright stars. The principal constellation of this region is *Orion* (the hunter), probably the best known constellation in the entire sky, with the exception of the big dipper. This figure is well known to navigators in both northern and southern hemispheres, as the belt of *Orion* lies almost exactly on the celestial equator.



Map (4)

- The above map (4) represents the celestial sphere on January1st at midnight local time of Alexandria/Egypt ≈ (30° N; 30° E).
- Number of navigation stars recognized are (11) stars.
- The same celestial sphere appears at the following times and dates:

Day/Month	Z.T.
Oct. 15th	0500
Nov. 1st	0400
Nov. 15th	0300
Dec. 1st	0200

Day/Month	Z.T.
Dec. 15th	0100
Jan. 1st	0000
Jan. 15th	2300
Feb. 1st	2200

Day/Month	Z.T.
Feb. 15th	2100
Mar. 1st	2000
Mar. 15th	1900

Celestial sphere revolves from East to West according to the apparent diurnal motion; therefor autumn stars begin to disappear through the western horizon. Constellation of *Orion* begins to appear above the eastern horizon. The constellation of *Orion* is the very famous one after *Ursa Major* since it has a lot of brightest stars in its neighborhood.

Constellation *Orion* consists of a square shape. In the middle of this shape there are 3 of (2^{nd} magnitude) stars known as the *Orion Belt* and align with the Equinoctial. This means that it rises at East point and sets at West point and being above the horizon for about 12 hours. Constellation of *Orion* is seen for both north and south latitudes observers.

- The star ***Alnilam*** is the middle star of the *Orion Belt*; this 2^{nd} magnitude star is tabulated in the daily page list of stars.
- The 4 stars of the square shape of *Orion* are ***Rigel*** in the SW corner and oppositely in the NE corner ***Betelguese*** ; both of them is 1^{st} magnitude star. West of ***Betelguese*** the 2^{nd} magnitude star ***Bellatrix*** is situated in the NW corner. The forth star is not tabulated in the daily page list of stars.

Several good navigational stars may be found by the use of *Orion*.

- If the line of the belt is continued to the westward, it leads near the 1^{st} magnitude reddish ***Aldebaran***, in the V-shaped head of *Taurus*. If the line of the belt is followed in the opposite direction, it leads almost to ***Sirius***, the brightest of all the stars. This is the principal star in the constellation of *Canis Major*, the hunter`s large dog.
- Starting with ***Sirius***, a rough circle can be drawn through ***Procyon***, ***Pollux*** and ***Castor***, ***Capella***, ***Aldebaran***, ***Rigel***, and back to ***Sirius***. All of these except ***Castor*** are 1^{st} magnitude stars.
- Stars ***Sirius*** and ***Betelguese*** compose an equilateral triangle with the 1^{st} magnitude star ***Procyon***. South of this triangle (south of Sirius) is the star ***Adhara*** (2^{nd} magnitude star).
- A line due north starting from the star ***Alnilam*** (middle of the *Orion Belt*), leads to the star ***Elnath***. The extension of this line reaches one of the brightest stars in the northern hemisphere named ***Capella***.
- A line through ***Betelguese*** starting from the star ***Alnilam*** (middle of the *Orion Belt*), leads to the stars ***Pollux*** and ***Castor***. Castor is not tabulated in the daily page list of stars.

In east horizon constellation Leo start to be seen with its bright stars ***Regulus*** and ***Denebola***.

In the NE direction *Ursa Major* appears again with its famous stars ***Dubhe***, ***Alioth*** and ***Alkaid*** which has a low altitude.

The navigational stars associated with *Orion Constellation* are (11) stars.

Alnilam, Rigel, Betelguese, Bellatrix, Aldebaran, Sirius, Adhara, Procyon, Elnath, Capella and Pollux.

The following map of the spring sky is the same map in the next page but without names of the navigation stars. This is to help student to identify and name the navigation stars.

Local times of locking for star maps in the 1st day and 15th day of every month.

October		November		December		January		February		March		April		May		June		July		August		September	
1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15
	Map (4) Stars of Northern Winter																						
	0500	0400	0300	0200	0100	0000	2300	2200	2100	2000	1900												
						Map (1) Stars of Northern Spring																	
						0600	0500	0400	0300	0200	0100	0000	2300	2200	2100	2000							
													Map (2) Stars of Northern Summer										
													0500	0400	0300	0200	0100	0000	2300	2200	2100	2000	1900
																			Map (3) Stars of Northern Autumn				
																			0500	0400	0300	0200	0100
Map (3) Stars of Northern Autumn																							
0000	2300	2200	2100	2000	1900																		

Concept of Time

Searching for a Unit of Measuring Time

Introduction:

For a unit to be used in measuring a certain phenomena, it must covers two requirements:

- It must be constant in value under all conditions.
- It must agree with our daily affairs.

For such a unit to measure the time phenomena; the approach was the length of the interval of rotation of the Earth around its axis. The length of this interval is known as the day! But what day?

The name of the day is dependent on the body used in detecting the interval of rotation of the Earth. So we have three definitions for three different days:

1- The apparent solar day; relative to the sun
2- The lunar day; relative to the moon.
3- The sidereal day; relative to the vernal equinox point.

A. *The Apparent Solar Day*

"It is the interval between two successive transits of the true sun`s center across the same meridian".

Referring to the requirements of a measuring unit , we find the following :

- The Apparent Solar Day is not fixed.
- The apparent solar day agrees with our daily affairs.

Thus the Apparent Solar Day is not a perfect time keeper.

B. ***The Lunar Day***

"It *is the interval between two successive transits of the moon`s center across the same meridian ".*

Referring to the requirements of a measuring unit, we find the following:

- The Lunar day is not fixed.
- The Lunar day is not agrees with our daily affairs.

Thus the Lunar day is not a perfect time keeper.

C. ***The Sidereal Day***

"It *is the interval between two successive transits of the Vernal equinox point (♈) across the same meridian ".*

Referring to the requirements of a measuring unit, we find the following :

- The Sidereal day is absolutely fixed.
- The Sidereal day is not agreed with our daily affairs.

Thus the Sidereal day is not a perfect time keeper for our daily life, but it is divided into 24 hours and every minute into 60 seconds and so and used in observatories as sidereal units of time.

The above discussion is summarized in the following table:

Unit	Constancy	Agreement with our daily affairs
Apparent Solar Day	Not fixed	Agree with our daily affairs
Lunar Day	Not fixed	Not agree with our daily affairs
Sidereal Day	fixed	Not agree with our daily affairs

Regarding the previous discussion, summarized above, we conclude that it is necessary to search for another unit to measure time.

We start again with the motion of the true sun in the ecliptic. Why this motion did not give us a perfect time- keeper? .The answer of this question is that the motion of the true sun is not a perfect time-keeper for two reasons:

1) According to the 2nd law of ***Kepler***, the true sun moves around the earth (apparently) in an ellipse; this means that its motion is not uniform. In another words it moves in the ecliptic with a non- uniform speed.
2) The true sun moves in the plane of the ecliptic whilst the Earth rotates in the plane of the equinoctial; this means that if the sun moves in the ecliptic with a uniform speed, then its projected motion in the equinoctial plane will not be uniform due to the continuous change in Sun`s declination.

So this problem is solved in two steps:

- We define a fictitious sun moves in the Ecliptic with a uniform speed equals to the average speed of the true sun. This is the ***dynamical mean sun*** .By this definition we reduce the eccentricity of the orbit.
- We define another fictitious sun moves in the Equinoctial with the same speed as that of the dynamical mean sun. This is the ***astronomical mean sun*** (for simplicity ***mean sun***⊕). By this definition we reduce the obliquity of the Ecliptic.

Now we have a *fictitious sun* moves in the equinoctial with a uniform speed related to the speed of the true sun in the Ecliptic.

The above discussion is summarized in the following tables:

1st step to reduce the eccentricity.

Body	*Orbit*	*Speed*
True Sun	Ecliptic	Non-uniform
Dynamical Mean Sun	Ecliptic	Uniform (equals average speed of true sun)

2nd step to reduce the obliquity.

Body	*Orbit*	*Speed*
Dynamical Mean Sun	Ecliptic	Uniform (equals average speed of true sun)
Astronomical Mean Sun	Equinoctial	Uniform (equals average speed of true sun)

So we can define a *new day* known as the mean solar day; which the principal unit for measuring solar time as follows:

The Mean Solar Day:

"It is the interval between two successive transits of the mean sun across the same meridian."

Referring to the requirements of a measuring unit, we find the following:

- This interval is absolutely fixed (by definition).
- The maximum difference between the Hour Angle of each of true sun and mean sun is about 17 minutes. So the mean solar day agrees with our daily affairs.

The mean solar day is divided into 24mean solar hour and every hour is divided into 60 mean solar minute and so. These are S***olar Units of Time***

Definitions of Time

Following to determine a suitable unit for measuring time ; we can define three different kinds of time as follows :

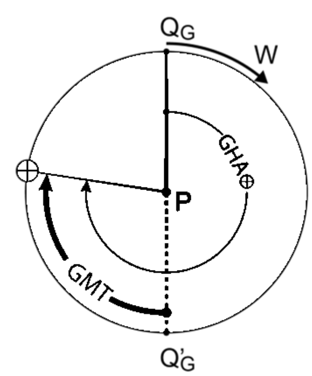
1) Mean solar time which is related to the motion of mean sun ⊕.
2) Apparent solar time which is related to the motion of true sun ⊙.
3) Sidereal time which is related to the motion of the vernal equinox point ♈

Greenwich Mean Time (G.M.T.):

" *It is the angle at the celestial pole contained between the lower meridian of Greenwich and the meridian of the mean sun, measured in westward direction starting from the lower meridian of Greenwich and expressed in units of time* . "

Relation between G.M.T. and G.H.A. of Mean Sun⊕ :
The G.M.T. is measured from the lower meridian of Greenwich whilst the G.H.A. is measured from the upper meridian of Greenwich; so:

UT (GMT) = G.H.A. ⊕ ± 12h
G.H.A. ⊕ = UT (GMT) ± 12h



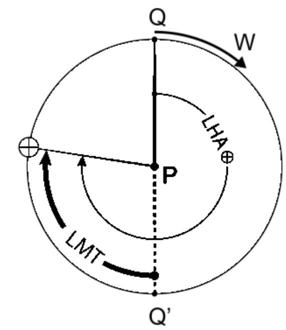
Local mean Time (L.M.T.):

"*It is the angle at the celestial pole contained between the lower meridian of the observer and the meridian of the mean sun, measured in westward direction starting from the lower meridian of the observer and expressed in units of time* " .

Relation between L.M.T. and L.H.A. of Mean Sun⊕ :

The L.M.T. is measured from the lower meridian of the observer whilst the L.H.A. is measured from the upper meridian of the observer ; so :

L.M.T. = L.H.A. ⊕ ± 12h
L.H.A. ⊕= L.M.T. ± 12h

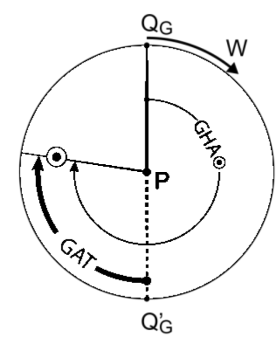


Greenwich Apparent Time (G.A.T.):

" *It is the angle at the celestial pole contained between the lower meridian of Greenwich and the meridian of the true sun, measured in westward direction starting from the lower meridian of Greenwich and expressed in units of time* . "

Relation between G.A.T. and G.H.A. of True Sun⊙ :
The G.A.T. is measured from the lower meridian of Greenwich whilst the G.H.A. is measured from the upper meridian of Greenwich ; so :

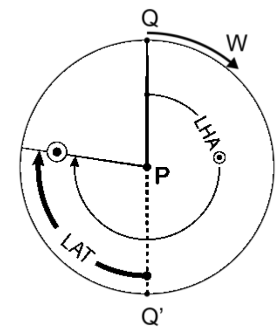
G.A.T = G.H.A. ⊙ ± 12h
G.H.A. ⊙= G.A.T ± 12h



Local apparent Time (L.A.T.):

"*It is the angle at the celestial pole contained between the lower meridian of the observer and the meridian of the true sun, measured in westward direction starting from the lower meridian of the observer and expressed in units of time* " .

Relation between L.A.T. and L.H.A. of Mean Sun⊙ :



The L.A.T. is measured from the lower meridian of the observer whilst the L.H.A. is measured from the upper meridian of the observer; so:

L.A.T. = L.H.A. ⊙ ± 12h
L.H.A. ⊙= L.A.T. ± 12h

Greenwich Sidereal Time (G.S.T.):

" *It is the angle at the celestial pole contained between the upper meridian of Greenwich and the meridian of the vernal equinox point , measured in westward direction starting from the upper meridian of Greenwich and expressed in units of time* . "

Relation between G.S.T. and G.H.A. of vernal equinox point ♈:
The G.S.T. is measured from the upper meridian of Greenwich and the G.H.A. is measured from the upper meridian of Greenwich; so:

G.S.T = G.H.A. ♈
G.H.A. ♈= G.A.T

Local Sidereal Time (L.S.T.):

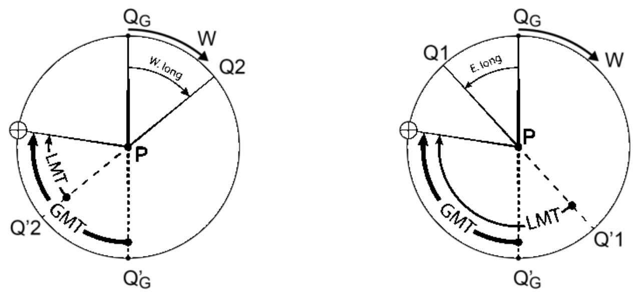
" *It is the angle at the celestial pole contained between the upper meridian of the observer and the meridian of the vernal equinox point , measured in westward direction starting from the upper meridian of the observer and expressed in units of time* . "

Relation between L.S.T. and L.H.A. of vernal equinox point ♈:
The L.S.T. is measured from the upper meridian of the observer and the L.H.A. is measured from the upper meridian of the observer; so:

L.S.T = L.H.A. ♈
L.H.A. ♈= L.A.T

Note:
Sidereal Time is reckoned *by Sidereal Clocks in observatories.*

Relation between L.M.T. and UT (G.M.T)



In figure (1) Left

$< Q`_G M$ represents UT (G.M.T) ---------------- (a)

$< Q`_1 M$ represents L.M.T. ---------------- (b)

$< Q`_G Q`_1 = < Q_G Q_1$ = Long. West ---------------- (c)

From (a), (b) and (c) we have:

$$\text{L.M.T.} = \text{UT (G.M.T.)} - \text{Long.}_{\text{West}} \qquad \text{---------- (1)}$$

In figure (2) right

$< Q`_G M$ represents UT (G.M.T) ---------------- (d)

$< Q`_2 M$ represents L.M.T. ---------------- (e)

$< Q`_G Q`_2 = < Q_G Q_2$ = Long. East ---------------- (f)

From (d), (e) and (f) we have:

$$\text{L.M.T.} = \text{UT (G.M.T.)} + \text{Long. East} \qquad \text{--------- (2)}$$

From equations (1) & (2) we have:

$$\text{L.M.T.} = \text{UT (G.M.T.)} \pm \text{Long}\,\frac{E}{W}$$

$$\text{UT (G.M.T.)} = \text{L.M.T.} \pm \text{Long}\,\frac{W}{E}$$

By the same procedure we have:

$$\text{L.A.T.} = \text{G.A.T.} \pm \text{Long}\,\frac{E}{W}$$

$$\text{G.A.T.} = \text{L.A.T.} \pm \text{Long}\,\frac{W}{E}$$

And:

$$\text{L.S.T.} = \text{G.S.T.} \pm \text{Long}\,\frac{E}{W}$$

$$\text{G.S.T.} = \text{L.S.T.} \pm \text{Long}\,\frac{W}{E}$$

Equation of Time

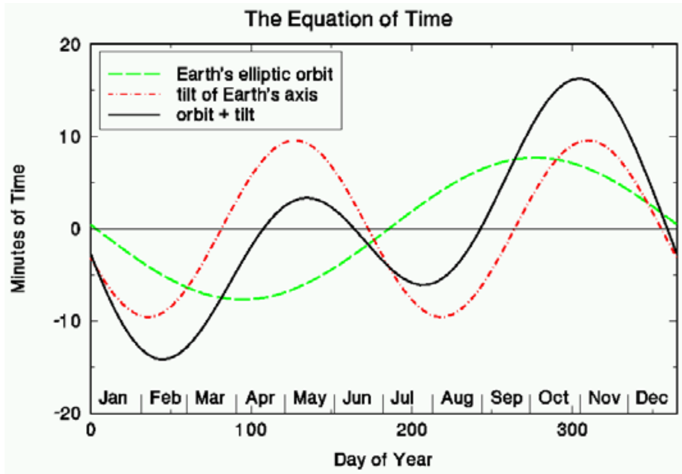
In nautical astronomy it is often required to convert from mean time to the hour angle of the true sun, for problems of this nature it is necessary to know the so-called equation of time, by which is meant the difference between mean time and apparent time; reckoning them from one and the same meridian.
This difference is numerically equal to the arc of the equator between the meridians of the mean sun and true sun.
Eq. of time = H.A. ⊙ - H.A. ⊕
= R.A. ⊕ - R.A.⊙
This means that the Eq. Of time is numerically equal to the difference of the hour angles of the true and the mean suns; or the difference of the right ascensions of the mean and true suns.
The sign (-) is given if the meridian of the mean sun is diurnal motion is ahead of the meridian of the true sun, and (+) if behind.
The Eq. of time is the resultant of two components; the 1st is due to the reduction of the motion of the true sun on the ecliptic to be a uniform motion. This component is called equation of the center or component due to eccentricity (E_1) .The 2ndcomponent is due to the reduction to the equator. This component is called the component due to obliquity (E_2).

The equations of E_1 and E_2 are out of the scope of this text, but the curves representing them are shown; from which we notice that:

- E_1 is zero near 3rd January (the farthest distance between Sun and Earth) and 5thJuly the least distance between them.
- E_2 is zero in the 4-days of Equinoxes and solstices.
- The overall quantity $E = E_1 + E_2$ is zero four times a year; namely15thApr. , 14thJun, 1stSept and 25thDec.
- Also it has four extreme values at 11th Feb. (+ 14.4m); 26th Jul. (+6.4m); 15th May (-3.8 m) and finally 3rd Nov. (-16.4 m).
- This is shown in the following table.

date	Apr. 15th	Jun. 14th	Sep. 1st	Dec. 25th
Eq. of time	00.0m	00.0m	00.0m	00.0m

date	Feb. 11th	May 25th	Jul 26th	Nov. 3rd
Eq. of time	+14.4m	-03.8m	+6.4m	-16.4m



- The above figure shows the curve of the equation of time E; the curve of the eccentricity component (E_1) and the curve of the obliquity component E_2.

Solved Example (1):

It was noticed that the sun crosses the upper meridian of a certain observer on board a ship at the noon of Feb. 11th.
Where:

- Long. Was 135° 12`.0 W;
- Equation of time was (+ 4m 04s).

Calculate each of; L.M.T. and G.M.T. of this phenomena.
Solution:

L.A.T.	12h 00m 00s Feb. 11th
Eq. of time	(-) 04m 04s
L.M.T.	11h 55m 56s Feb. 11th
Long. (+)	09h 00m 48s
G.M.T.	20h 56m 44s Feb. 11th

Solved Example (2):

Sun was observed when crossing the upper meridian of Greenwich at G.M.T. 12h 08m 04s.
Calculate the value and sign of the Equation of time.
Solution:

G.A.T.	12h 00m 00s
G.M.T.	12h 08m 04s
Eq. of time	(-) 08m 04s

Solved Example (3):

Sun was observed when crossing the upper meridian of Greenwich at G.M.T. 11h 58m 44s.
Calculate the value and sign of the Equation of time.
Solution:

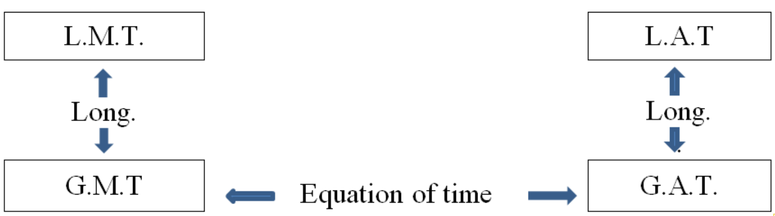
G.A.T.	12h 00m 00s
G.M.T.	11h 58m 44s
Eq. of time	(+) 01m 16s

Extraction of the Equation of Time from N.A. Tables:

The Equation of time is given twice a day in the Nautical Almanac Tables; 1st value at Greenwich Time 00h and the second at Greenwich Time 12h without sign.

We can apply the suitable sign by comparing between the L.M.T. & L.A.T. of Meridian Passage of the sun. L.M.T. mentioned is given daily under the column labeled Mer. Pass. While the L.A.T., at the same phenomena is known to be 1200 h. The following solved examples show the procedure of application.

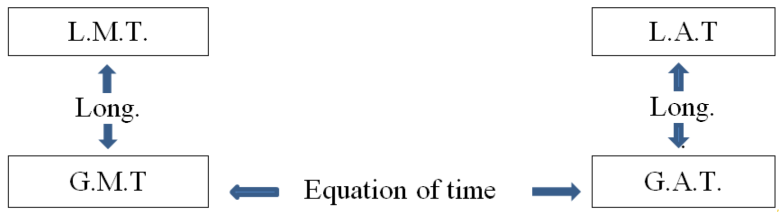
The following flow chart is useful in solving problems of time relations:



Solved Example (1)

At a certain moment the universal time G.M.T. was recorded
11h 50m 18s Apr. 20^{th} 1990.
Calculate the L.M.T. at the same moment for an observer in
Long. 110° 18`.0 W.

Solution:



1159	G.M.T.	11h 50m 18s Apr. 20^{th}
	Eq. of time	+ 01m 04s
1200	G.A.T.	11h 51m 22s Apr. 20^{th}
	Long. E/W	07h 21m 12s
	L.A.T.	04h 30m 10s

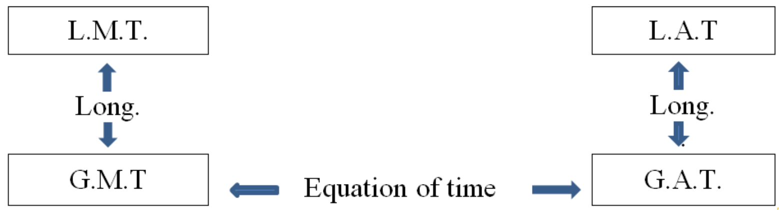
Table extracted from N.A. Tables

Day	Sun Eq. of time.		Mer. Pass.
	00h	12h	
19	00^m 45^s	00^m 51^s	1159
20	00^m 58^s	01^m 04^s	1159
21	01^m 10^s	01^m 16^s	1159

Solved Example (2)

At a certain moment the G.A.T. was recorded 08h 12m 40s Jul. 1st, 1990.
Calculate the L.M.T. at the same moment for an observer in Long. 175° 20`.0 W.

Solution:



1200	G.A.T.	08h 12m 40s Jul. 1st
	Eq. of time	+ 03m 45s
1204	G.M.T.	08h 16m 25s Jul. 1st
	Long. (-)	11h 41m 20s
	L.M.T.	20h 35m 05s Jun. 30th

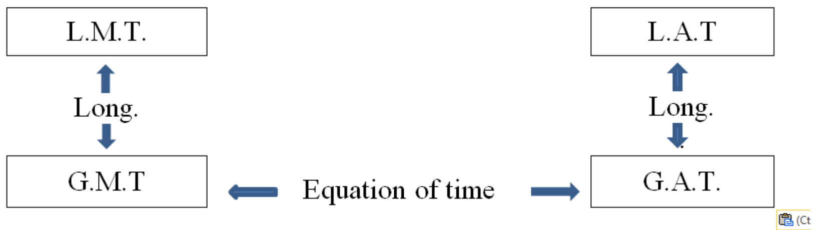
Table extracted from N.A. Tables

Day	Sun Eq. of time.		Mer. Pass.
	00h	12h	
30	$03^m\ 29^s$	$03^m\ 35^s$	1204
1	$03^m\ 41^s$	$03^m\ 47^s$	1204
2	$03^m\ 53^s$	$03^m\ 59^s$	1204

Solved Example (3)

At a certain moment the L.M.T. was recorded 11h 04m 48s Nov. 27th;1990, for an observer in long. 170° 12`.0 W. Calculate the G.A.T. at the same moment

Solution:



	L.M.T.	11h 04m 48s Nov. 27th
	Long.	11h 20m 48s
1148	G.M.T.	22h 25m 36s Nov. 27th
	Eq. of time	12m 17s
1200	G.A.T.	22h 37m 53s Nov. 27th

Table extracted from N.A. Tables

Day	Sun Eq. of time. 00h	Sun Eq. of time. 12h	Mer. Pass.
27	$12^m\ 35^s$	$12^m\ 25^s$	1148
28	$12^m\ 16^s$	$12^m\ 06^s$	1148
29	$11^m\ 55^s$	$11^m\ 45^s$	1148

Zone Time

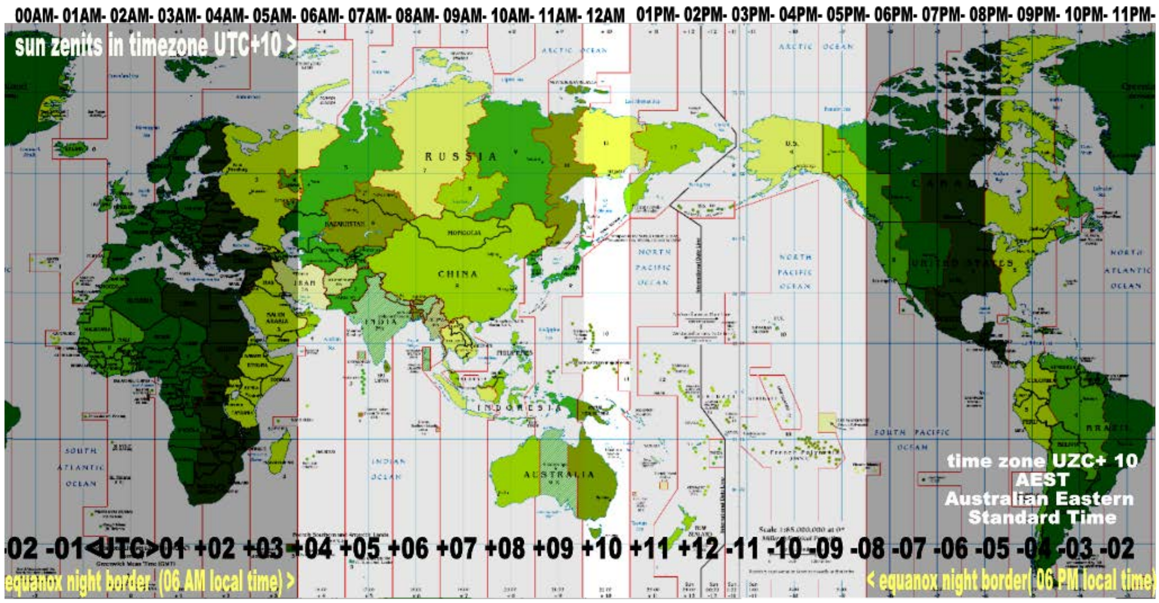
- There are 360 meridians of longitude 1° intervals round the earth and it would be most confusing if there were a separate L.M.T. for each meridian. For this reason the zone time system have been established.
- Under the zone time system, the earth's surface is divided into zones each of which is 15° of longitude wide, extending from pole to pole.
- Zone zero [0] extends from long. 7° 30' W to long. 7° 30' E; so that Greenwich meridian is the mid-meridian of this zone. Within the boundaries of zone [0] the zone time is G.M.T.
- Zone [+1] extends from long. 7° 30' W to long. 22º 30' W; its mid-meridian being 15° W. Within the boundaries of this zone the time kept is 1 hour less than G.M.T. ; and corresponds to the L.M.T. of long. 15° W. This zone is called zone [+1] because an observer on board a ship anywhere in this zone keeping the time of zone [+1] merely has to add one hour to this zone to obtain G.M.T. in accordance to the equation :

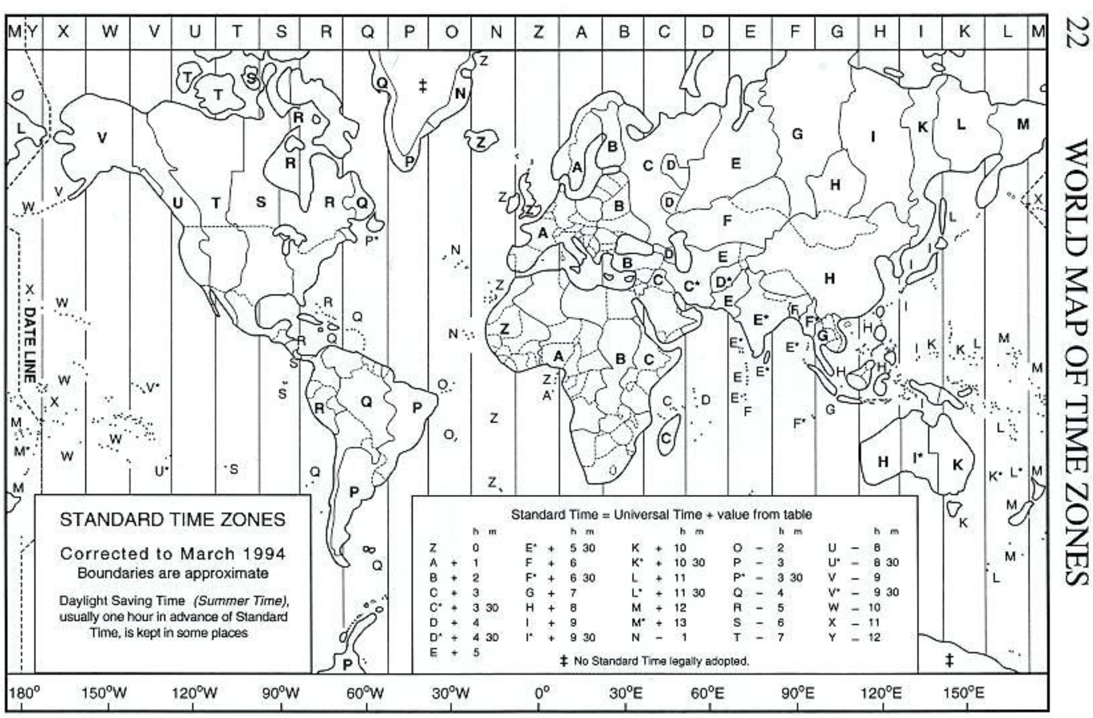
$$G.M.T. = L.M.T. + Long.\ W$$

- Zone [+2] extends from long. 22° 30' W to long. 37° 30' W., its mid-meridian being long. 30° W. It is clear that, this time is less than G.M.T. by 2-hours, so when keeping this zone time onboard a ship; 2 hours must be added to zone time to obtain G.M.T.
  By the same procedure zone areas extended westerly up to the special area [12] of mid long. 180°.
- Zone [-1] extends from long. 7° 30' E up to long. 22° 30' E , its mid-meridian being 15° E. Within the boundaries of this zone the time kept is 1 hour ahead of G.M.T. ; and corresponds to the L.M.T. of long. 15° 00` E. This zone is called zone [-1] because an observer on board a ship anywhere in this zone keeping the time of zone [-1] merely has to subtract one hour to this zone to obtain G.M.T. in accordance to the equation :

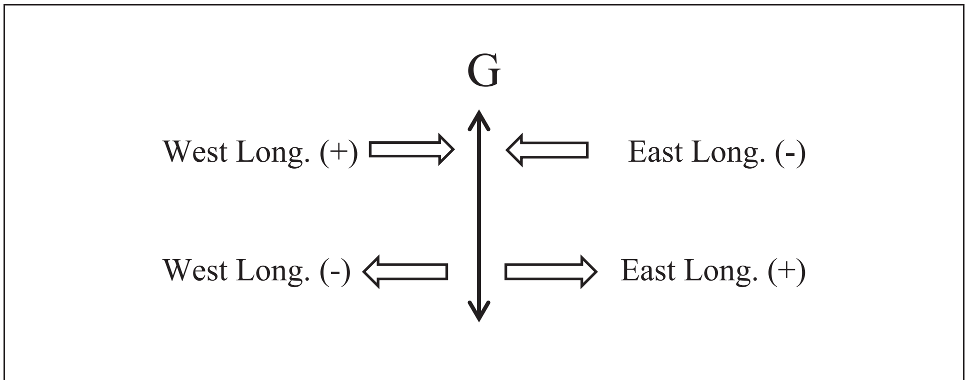
$$G.M.T. = L.M.T. - Long.\ E$$

- Zone [-2] extends from long.22° 30'E up to long. 37° 30'E,and the time kept in this zone is the L.M.T. of the middle long. 30° 00` E. It is clear that this time is ahead of G.M.T. by 2- hours . When keeping the zone time of zone [-2]; 2 hours, must be subtracted from zone time to obtain G.M.T. By the same procedure zone areas extended easterly up to the special area [12] of mid long. 180°.


00AM- 01AM- 02AM- 03AM- 04AM- 05AM- 06AM- 07AM- 08AM- 09AM- 10AM- 11AM- 12AM 01PM- 02PM- 03PM- 04PM- 05PM- 06PM- 07PM- 08PM- 09PM- 10PM- 11PM-
sun zenits in timezone UTC+10 >
RUSSIA
CHINA
INDIA
INDONESIA
AUSTRALIA
time zone UZC+ 10
AEST
Australian Eastern
Standard Time
-02 -01<UTC>01 +02 +03 +04 +05 +06 +07 +08 +09 +10 +11 +12 -11 -10 -09 -08 -07 -06 -05 -04 -03 -02
equanox night border (06 AM local time) >
< equanox night border(06 PM local time)


22
WORLD MAP OF TIME ZONES
M Y X W V U T S R Q P O N Z A B C D E F G H I K L M
DATE LINE
STANDARD TIME ZONES
Corrected to March 1994
Boundaries are approximate
Daylight Saving Time (Summer Time), usually one hour in advance of Standard Time, is kept in some places
Standard Time = Universal Time + value from table
Z 0; A + 1; B + 2; C + 3; C* + 3 30; D + 4; D* + 4 30; E + 5
E* + 5 30; F + 6; F* + 6 30; G + 7; H + 8; I + 9; I* + 9 30
K + 10; K* + 10 30; L + 11; L* + 11 30; M + 12; M* + 13; N − 1
O − 2; P − 3; P* − 3 30; Q − 4; R − 5; S − 6; T − 7
U − 8; U* − 8 30; V − 9; V* − 9 30; W − 10; X − 11; Y − 12
‡ No Standard Time legally adopted.
180° 150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E

A. Relation between GREENWICH &LOCAL Phenomena



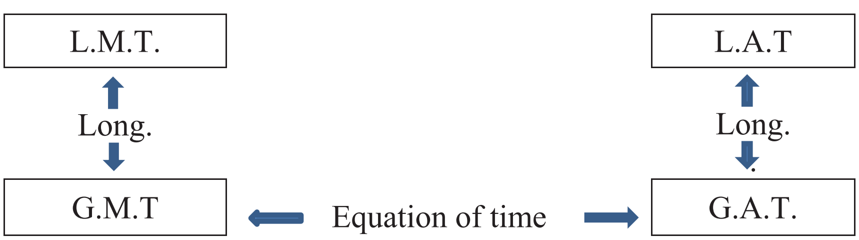
G.M.T. = L.M.T. ± Long. $\frac{W}{E}$	L.M.T. = G.M.T. ± Long. $\frac{E}{W}$
G.A.T. = L.A.T. ± Long. $\frac{W}{E}$	L.A.T. = G.A.T. ± Long. $\frac{E}{W}$
G.D. = Z.T. ± Z.N. $\frac{W}{E}$	Z.T. = G.D. – (± Z.N. $\frac{W}{E}$)

B. Relation between G.M.T.; G.A.T. & Equation of time:

$$\text{G.M.T.} = \text{G.A.T} \pm \text{Equation of time} \begin{cases} + \; if \; LMT \; mer \; pass > 1200 \\ - \; if \; LMT \; mer \; pass < 1200 \end{cases}$$

$$\text{G.A.T.} = \text{G.M.T} \pm \text{Equation of time} \begin{cases} + \; if \; LMT \; mer \; pass < 1200 \\ - \; if \; LMT \; mer \; pass > 1200 \end{cases}$$

C. Relation between types of time:



How to obtain ZN (Zone Number) of ship`s position:

In order to find the zoon in which the ship is situated ; the quickest method is to convert the longitude of its position into units of time (dividing by 15) then considering the nearest whole hour as Z.N. ; with minus sign (-) for East Longitude and positive sign (+) for west Long.

Solved Example (1):

Find the Zone Number Z.N. of a ship in DR position (33° 32` N; 133° 55` W).

Answer:

Long. 133° 55` = 8h 55m 40s

i.e. Z. N. = (+ 9)

Solved Example (2):

Find the Zone Number Z.N. of a ship in DR position (53° 32` N; 105° 50` E).

Answer:

Long. 105° 50` = 7h 03m 20s

i.e. Z. N. = (- 7)

Relation between Zone Time and Universal Time

Regarding the following relation between UT (G.M.T.) and Local Mean Time (L.M.T.)

$$\text{UT (G.M.T.)} = \text{L.M.T.} \pm \text{Long } \frac{W}{E}$$

We can write the relation between UN (G.M.T.) and Zone Time (Z.T.) in the manner as follows:

$$\text{UT (G.M.T.)} = \text{Z.T.} \pm \text{Z.N.} \frac{W}{E}$$

Solved Example (1):

Z.T. was recorded 1720 May 15th; for an observer in DR Long. 29° 20` E.
Obtain UT (G.M.T.) at the same moment.

Solution:

Z.T.	1720 May 15th
Z.N. (-)	2
UT(G.M.T.)	1520 May 15th

Solved Example (2):

Z.T. was recorded 2040 Aug. 20th ; for an observer in DR Long. 171° 05` W.
Obtain UT (G.M.T.) at the same moment.

Solution:

Z.T.	2040 Aug.20th
Z.N. (+)	11
UT(G.M.T.)	0740 Aug.21st

Solved Example (3):

Z.T. was recorded 0519 Jan. 3rd; for an observer in DR Long. 160° 12` E.
Obtain UT (G.M.T.) at the same moment.

Solution:

Z.T.	0519 Jan. 3rd
Z.N. (-)	11
UT(G.M.T.)	1819 Jan. 2nd

Standard Time:

- Standard time is a modified type of zone time which has been established throughout the world. So that wherever possible, the same time is kept in the same country.
- Standard time differs from zone time only in the fact that the boundaries of the country or state, not meridians, are the limits of the standard time area.
- A list of standard time kept by all the nations and states of the world is given in the Nautical Almanac tables (pages 262-265).

As an example; India, keeps the standard time denoted (- 5h 30m) i.e.
to obtain UT (G.M.T.) you must subtract 5h 30m from the standard time.
(See next Page)

262

STANDARD TIMES (Corrected to September 1987)

LIST I—PLACES FAST ON UTC (mainly those EAST OF GREENWICH)

The times given below should be *added* to UTC to give Standard Time. / *subtracted* from Standard Time to give UTC.

	h	m
Admiralty Islands	10	
Afghanistan	04	30
Albania*	01	
Algeria	01	
Amirante Islands	04	
Andaman Islands	05	30
Angola	01	
Annobon Island	01	
Australia		
Australian Capital Territory*	10	
New South Wales[1]*	10	
Northern Territory	09	30
Queensland	10	
South Australia*	09	30
Tasmania*	10	
Victoria*	10	
Western Australia*	08	
Austria*	01	
Bahrain	03	
Balearic Islands*	01	
Banaba	11	30
Bangladesh	06	
Belgium*	01	
Benin (Dahomey)	01	
Botswana, Republic of	02	
Brunei	08	
Bulgaria*	02	
Burma	06	30
Burundi	02	
Cameroon Republic	01	
Caroline Islands, west of long. E. 135°	09	
long. E. 135° to E. 150°	10	
long. E. 150° to E. 160°	11	
east of long. E. 160°	12	
Central African Republic	01	

	h	m
Djibouti	03	
Egypt, Arab Republic of	02	
Equatorial Guinea, Republic of	01	
Estonia	03	
Ethiopia	03	
Fernando Póo	01	
Fiji	12	
Finland*	02	
France*	01	
Friendly Islands	13	
Gabon	01	
Germany, East*	01	
West[3]*	01	
Gibraltar*	01	
Greece*	02	
Guam	10	
Holland (The Netherlands)*	01	
Hong Kong	08	
Hungary*	01	
India	05	30
Indonesia, Republic of		
Bali, Bangka, Billiton, Java, Madura, Sumatra	07	
Flores, Kalimantan, Lombok, Sulawesi, Sumba, Sumbawa, Timor	08	
Aru, Irian Jaya, Kai, Moluccas, Tanimbar	09	
Iran	03	30
Iraq*	03	
Israel*	02	
Italy*	01	
Japan	09	

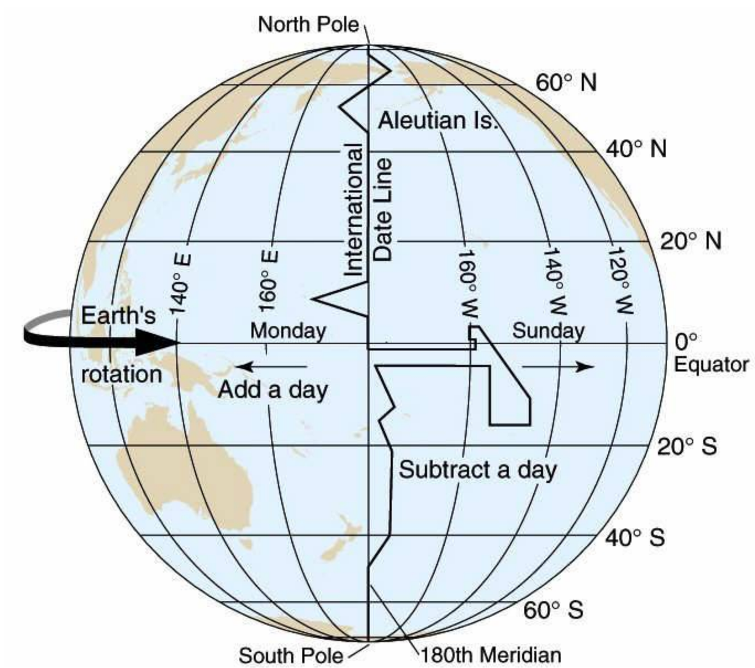
International Date Line:

- Due to the fact that; in zone timekeeping, the zone time increases one hour moving eastward and decreases one hour moving westward; there will be a single central meridian where the time difference along sides is 24-hours, i.e. one complete day.
- This meridian of changing date is the longitude 180°, and known as the International Date Line.
- At the same instant of time, there are two dates on the two sides of this Longitude and therefore one has to change date when crossing the line.

Change dates on a ship underway is done at the midnight following to the crossing according to the following rules:

Rule (1): *For ships sailing easterly, one date is repeated at the midnight following to the crossing.*

Rule (2): *For ships sailing westerly, one date is dropped at the midnight following to the crossing.*



Note: to avoid errors in determining UT(GMT) and correct date in calculations when crossing international date line , one should continue to reckon longitude above the longitude 180° E (or W) till the following midnight. This exceptional application is illustrated in the next three solved examples.

Solved Example (1)

Assuming that:
The 1st observation of the sun was made in Long. 179° 47` E; at Z.T. 1440 Aug. 7th.
And the 2nd observation of the sun was made in Long. 179° 16` W; at Z.T. 1730 Aug. 7th.
Find the UT (G.M.T.) for each observation.
Note:
When obtaining UT (G.M.T.) in the 2nd observation; before midnight; consider the long. 180° 44` E.

Solution:

$Z.T._1$	1440 Aug. 7th
Z.N. (-)	12
UT_1	0240 Aug. 7th

$Z.T._2$	1730 Aug. 7th
Z.N. (-)	12
UT_2	0530 Aug. 7th

Solved Example (2)

A vessel steering 140° True, crossed the international date line at about Z.T. 1600 Sept. 15th.
Given that Z.N. (- 12), change the date at the following midnight.

Solution:

Since the vessel is sailing easterly; the date at the following midnight will repeated to be Sept. 15th. (Instead of Sept. 16th).

Solved Example (3)

A vessel steering 240° True, crossed the international date line at about Z.T. 1015 May 21st.
Given that Z.N. (+ 12), change the date at the following midnight.

Solution:

Since the vessel is sailing westerly; then at the following midnight one day will be dropped and the date will be May 23rd (instead of May 22nd).

Estimated Times of Ship`s Departure or Arrival

Navigators need to remember some useful calculations necessary to solve problems of obtaining *Estimated Times of Departure or Arrival and speed.*
These are:

- How to calculate Steaming Time of a ship:
- How to add (subtract) dates:

The following is the procedures required to solve these problems.

How to calculate Steaming Time of a ship:

Steps

1. Divide the distance run by speed to get the actual steaming hours.
2. Add the hours in hand to actual steaming hours to obtain the total steaming hours.
3. Divide the total steaming hours by 24h to convert to days.
4. Consider the round figure of days as the complete steaming days; the remainder is a fraction of a day.
5. Multiply the remainder fraction of the day by 24h to convert it into hours, minutes and seconds. (Round off to the nearest minute).
6. The steaming time : days : hours : minutes is now obtained

Application:

Calculate the total Steaming Time of sailing where:

Total distance runs	3050Miles
Steaming speed	18knots
Hours in hand	10h

Steps:

3050 ÷ 18

Actual steaming hours	169.44444h		
Hours in hand	+10		
Total steaming hours	179.44444h		
	÷24		
Total days	7.47685d		
Complete days		→	7d
Remainder fraction of day	0.47685d		
	x24		
Fraction of day in hours	11.44444h	→	11h 26m 40s

Answer: steaming time 7d: 11h: 27m

How to add (subtract) dates:

From Calendar Table page (5) *Nautical Almanac Tables*
Proceed as follows;

- Convert the date in question into a day of the year.
- Add (or Subtract) the days in question to the day of the year; you have a new day of the year.
- Convert the new day of the year into a date again.

CALENDAR, 1990

5

DAYS OF THE WEEK AND DAYS OF THE YEAR

Day of Month	JAN. Week	JAN. Year	FEB. Week	FEB. Year	MAR. Week	MAR. Year	APR. Week	APR. Year	MAY Week	MAY Year	JUNE Week	JUNE Year
1	M.	1	Th.	32	Th.	60	Su.	91	Tu.	121	F.	152
2	Tu.	2	F.	33	F.	61	M.	92	W.	122	Sa.	153
3	W.	3	Sa.	34	Sa.	62	Tu.	93	Th.	123	Su.	154
4	Th.	4	Su.	35	Su.	63	W.	94	F.	124	M.	155
5	F.	5	M.	36	M.	64	Th.	95	Sa.	125	Tu.	156
6	Sa.	6	Tu.	37	Tu.	65	F.	96	Su.	126	W.	157
7	Su.	7	W.	38	W.	66	Sa.	97	M.	127	Th.	158
8	M.	8	Th.	39	Th.	67	Su.	98	Tu.	128	F.	159
9	Tu.	9	F.	40	F.	68	M.	99	W.	129	Sa.	160
10	W.	10	Sa.	41	Sa.	69	Tu.	100	Th.	130	Su.	161
11	Th.	11	Su.	42	Su.	70	W.	101	F.	131	M.	162
12	F.	12	M.	43	M.	71	Th.	102	Sa.	132	Tu.	163
13	Sa.	13	Tu.	44	Tu.	72	F.	103	Su.	133	W.	164
14	Su.	14	W.	45	W.	73	Sa.	104	M.	134	Th.	165
15	M.	15	Th.	46	Th.	74	Su.	105	Tu.	135	F.	166
16	Tu.	16	F.	47	F.	75	M.	106	W.	136	Sa.	167
17	W.	17	Sa.	48	Sa.	76	Tu.	107	Th.	137	Su.	168
18	Th.	18	Su.	49	Su.	77	W.	108	F.	138	M.	169
19	F.	19	M.	50	M.	78	Th.	109	Sa.	139	Tu.	170
20	Sa.	20	Tu.	51	Tu.	79	F.	110	Su.	140	W.	171
21	Su.	21	W.	52	W.	80	Sa.	111	M.	141	Th.	172
22	M.	22	Th.	53	Th.	81	Su.	112	Tu.	142	F.	173
23	Tu.	23	F.	54	F.	82	M.	113	W.	143	Sa.	174
24	W.	24	Sa.	55	Sa.	83	Tu.	114	Th.	144	Su.	175
25	Th.	25	Su.	56	Su.	84	W.	115	F.	145	M.	176
26	F.	26	M.	57	M.	85	Th.	116	Sa.	146	Tu.	177
27	Sa.	27	Tu.	58	Tu.	86	F.	117	Su.	147	W.	178
28	Su.	28	W.	59	W.	87	Sa.	118	M.	148	Th.	179
29	M.	29			Th.	88	Su.	119	Tu.	149	F.	180
30	Tu.	30			F.	89	M.	120	W.	150	Sa.	181
31	W.	31			Sa.	90			Th.	151		

Day of Month	JULY Week	JULY Year	AUG. Week	AUG. Year	SEPT. Week	SEPT. Year	OCT. Week	OCT. Year	NOV. Week	NOV. Year	DEC. Week	DEC. Year
1	Su.	182	W.	213	Sa.	244	M.	274	Th.	305	Sa.	335
2	M.	183	Th.	214	Su.	245	Tu.	275	F.	306	Su.	336
3	Tu.	184	F.	215	M.	246	W.	276	Sa.	307	M.	337
4	W.	185	Sa.	216	Tu.	247	Th.	277	Su.	308	Tu.	338
5	Th.	186	Su.	217	W.	248	F.	278	M.	309	W.	339
6	F.	187	M.	218	Th.	249	Sa.	279	Tu.	310	Th.	340
7	Sa.	188	Tu.	219	F.	250	Su.	280	W.	311	F.	341
8	Su.	189	W.	220	Sa.	251	M.	281	Th.	312	Sa.	342
9	M.	190	Th.	221	Su.	252	Tu.	282	F.	313	Su.	343
10	Tu.	191	F.	222	M.	253	W.	283	Sa.	314	M.	344
11	W.	192	Sa.	223	Tu.	254	Th.	284	Su.	315	Tu.	345
12	Th.	193	Su.	224	W.	255	F.	285	M.	316	W.	346
13	F.	194	M.	225	Th.	256	Sa.	286	Tu.	317	Th.	347
14	Sa.	195	Tu.	226	F.	257	Su.	287	W.	318	F.	348
15	Su.	196	W.	227	Sa.	258	M.	288	Th.	319	Sa.	349
16	M.	197	Th.	228	Su.	259	Tu.	289	F.	320	Su.	350
17	Tu.	198	F.	229	M.	260	W.	290	Sa.	321	M.	351
18	W.	199	Sa.	230	Tu.	261	Th.	291	Su.	322	Tu.	352
19	Th.	200	Su.	231	W.	262	F.	292	M.	323	W.	353
20	F.	201	M.	232	Th.	263	Sa.	293	Tu.	324	Th.	354
21	Sa.	202	Tu.	233	F.	264	Su.	294	W.	325	F.	355
22	Su.	203	W.	234	Sa.	265	M.	295	Th.	326	Sa.	356
23	M.	204	Th.	235	Su.	266	Tu.	296	F.	327	Su.	357
24	Tu.	205	F.	236	M.	267	W.	297	Sa.	328	M.	358
25	W.	206	Sa.	237	Tu.	268	Th.	298	Su.	329	Tu.	359
26	Th.	207	Su.	238	W.	269	F.	299	M.	330	W.	360
27	F.	208	M.	239	Th.	270	Sa.	300	Tu.	331	Th.	361
28	Sa.	209	Tu.	240	F.	271	Su.	301	W.	332	F.	362
29	Su.	210	W.	241	Sa.	272	M.	302	Th.	333	Sa.	363
30	M.	211	Th.	242	Su.	273	Tu.	303	F.	334	Su.	364
31	Tu.	212	F.	243			W.	304			M.	365

Application (1)
Find the number of days between April 24th and May 17th, 1984
Answer:

May 17th	→	138
Apr. 24th	→	115
Number of days		23^d

Application (2)
Add 19 days to Jun. 27th to find new date.

Jun. 27th	→	179
		+19
Jul. 16th	←	198

Application (3)
Subtract 23 days from Aug. 2nd to find new date.

Aug. 2nd	→	215
		- 23
Jul. 10th	←	192

SOLVED EXAMPLE (1)

A vessel is ordered to leave ***New Westminster*** at Z.T. Z.T. 1800 Oct. 18th; to arrive to ***Port Stanley***

- Distance apart is calculated to be 6530 Miles.
- Steaming speed is assumed to be 14.5 knots
- Hours to be kept in hand for facing bad weather and unexpected events are 10h.
- Position of Port ***New Westminster*** (49º 12` N ; 122º 55 W)
- Position of ***Port Stanley*** (40º 42` S; 145º 23 E).

Calculate the estimated time of arrival (E.T.A.).

ANSWER

Port A		ZT	1800 Oct 18th	
		ZN	+ 8	
	Dist.	6530		
	Speed	14.5 k		$19^d\ 04^h\ 21^m$
	In hand	10 h		
Port B		ZT	????	
		ZN	- 10	-

ZT of departure	1800 Oct 18th
ZN	+8
GD of departure	0200 Oct 19th → 292
Steaming time +	0421 19
GD of arrival	0621 Nov 7th ← 311
ZN (reversed)	10 (+)
ZT of arrival	1621 Nov 7th

SOLVED EXAMPLE (2)

A vessel is ordered to leave ***Port Walter***; to arrive to ***Port Hana Saki*** at Z.T. Z.T. 1300 May 10th.

- Distance apart is calculated to be 6800 Miles.
- Steaming speed is assumed to be 14.5 knots
- Hours to be kept in hand for facing bad weather and unexpected events are 10h.
- Position of ***Port Walter*** (56º 23` N ; 134º 40` W)
- Position of ***Port Hana Saki*** (43º 17` N; 145º 35` E).

Calculate the estimated time of departure (ETD).

ANSWER

Port A		ZT	????	
		ZN	+9	
	Dist.	6800		
	Speed	14.5 k		$19^d\ 22^h\ 58^m$
	In hand	10 h		
Port B		ZT	1300 May 10th	
		ZN	- 10	

ZT of arrival	1300 May 10th
ZN	10 (-)
GD of arrival	0300 May 10th → 130
Steaming time (-)	2258 19
GD of departure	0402 Apr 20th ← 110
ZN (reversed)	9 (-)
ZT of departure	1902 Apr 19th

SOLVED EXAMPLE (3)

A vessel is ordered to:
Leave ***Port Hana Saki*** at Z.T. 1315 Apr 19th
To arrive to ***Port Walter*** at Z.T. 1300 May 10th.

- Distance apart is calculated to be 6895 Miles.
- Hours to be kept in hand for facing bad weather and unexpected events are 12h.
- Position of ***Port Hana Saki*** (43º 17`.0 N; 145º 35`.0 E).
- Position of ***Port Walter*** (56º 23`.0 N; 134º 40`.0 W).

Calculate the steaming speed?

Answer:

Port A		ZT	1315 Apr 19th
		ZN	10 (-)
	Dist.	6895	
	Speed	?? k	
	In hand	12 h	
Port B		ZT	1300 May 10th
		ZN	9 (+)

ZT of dep.	1315 Apr 19th
ZN (-)	10
GD of dep.	0315 Apr 19th

ZT of Arrival	1300 May 10th
ZN (+)	9
GD of Arrival	2200 May 10th

GD of Arrival	2200 May 10th →	130
GD of departure (-)	0315 Apr 19th →	109
Interval	1845	21 days
Total steaming hours	(21x24)+(18)+(45/60)=522.75h	

Total steaming hours	522.75
Hours in hand (-)	12
Actual steaming hours	510.75

Speed = (6895 M / 510.75 h) = 13.5 knots

How to adjust GMT obtained from Chronometer time piece:

Chronometer

Marine Watch

The function of the Chronometer is to give accurate time in Greenwich. This is done by adding the error of the Chronometer (+ for slow and – for fast) to its reading as follows:

Chronometer Time →	Ch. T.	
Chronometer Error →	Ch. E.	
G.M.T.	G.M.T.	

Since the Chronometer dial reads only 12hours (see picture above); we must obtain as a first step the correct hours of time in Greenwich and the correct date. This is done as a guide step as follows:

1. Obtain ZT from Marine Watch. (In bridge or chart room).
2. Obtain ZN from DR long. on chart.
3. Apply the Equation G.D. = Z.T. ± Z.N. $\frac{W}{E}$;
4. Add 12h to G.M.T. if GD > 12h.

Zone Time →	Z. T.	
Zone Number →	Z.N.	
Greenwich date	G.D.	

Applications:

Application (1)

The following data were recorded:

- Z.T. 1725 on January15th ; 1990,
- Ship was in D.R. position (31º 15`.0 S; 125º 22`.0 W).
- Ch. Error 02m 56s fast
- Ch. Time 01h 27m 24s

Find the correct GMT.

Answer:

ZT	1725 Jan. 15th	
ZN	+8	
GD	0125 Jan. 16th	
Ch. Time	01h 27m 24s	
Ch. Error	02m 56s →	*Subtract Ch. Error **(fast)***
GMT	01h 24m 28s Jan. 16th →	*GD 0125 < 12h* *GD Jan. 16th*

Application (2)

The following data were recorded:

- Z.T. 2040 on September 13th ; 1990,
- Ship was in D.R. position (29º 30`.0 N; 46º 40`.0 W).
- Ch. Error 05m 14s fast
- Ch. Time 11h 45m 54s

Find the correct GMT.

Answer:

ZT	2040 Sept. 13th	
ZN	+3	
GD	2340 Sept. 13th	
Ch. Time	11h 45m 54s	
Ch. Error	05m 14s →	*Subtract Ch. Error **(fast)***
GMT	23h 40m 40s Sept. 13th →	*Add 12h since GD 2340 > 12h* *GD Sept. 13th*

Application (3)

The following data were recorded:

- Z.T. 1725 on January15th ; 1990,
- Ship was in D.R. position (31º 15`.0 S; 125º 22`.0 W).
- Ch. Error 02m 56s ***slow***
- Ch. Time 01h 27m 24s

Find the correct GMT.

Answer:

ZT	1725 Jan. 15th	
ZN	+8	
GD	0125 Jan. 16th	

Ch. Time	01h 27m 24s	
Ch. Error	02m 56s →	*Subtract Ch. Error* ***(slow)***
GMT	01h 30m 20s Jan. 16th →	*GD 0125 < 12h* *GD Jan. 16th*

Application (4)

The following data were recorded:

- Z.T. 1725 on January 16th ; 1990,
- Ship was in D.R. position (31º 15`.0 S; 125º 22`.0 E).
- Ch. Error 02m 56s ***slow***
- Ch. Time 09h 27m 24s

Find the correct GMT.

Answer:

ZT	1725 Jan. 16th	
ZN	-8	
GD	0925 Jan. 16th	

Ch. Time	09h 27m 24s	
Ch. Error	02m 56s →	*Subtract Ch. Error* ***(slow)***
GMT	09h 30m 20s Jan. 16th →	*GD 0925 < 12h* *GD Jan. 16th*

Nautical Almanac Tables

1- Object

The object of this Almanac is to provide, in a convenient form, the data required for the practice of celestial navigation at sea.

2- Principles

The main contents of the almanac consist of data from which the Greenwich Hour Angle (GHA) and Declination (Dec.) of all the bodies used for navigation can be obtained for any instant of Greenwich Mean Time (GMT), the Local Hour Angle (LHA) can then be obtained by means of the formula:

$$L.H.A = G.H.A \pm \text{longitude} \frac{E}{W}$$

The remaining data consist of:

Times of rising and setting of the sun and moon and times of twilight; miscellaneous calendar and planning data and auxiliary tables, including a list of standard times; corrections to be applied to observed altitude.

For the sun, moon and planets the GHA and Dec. are tabulated directly for each hour of (UT) GMT throughout the year. For the stars the Sidereal Hour Angle (SHA) is given, and the GHA is obtained from:

$$G.H.A\ star = G.H.A\ Aries + S.H.A\ star$$

The SHA and Dec. of the stars change slowly and may be regarded as constant over periods of several days. GHA (Aries) is tabulated for each hour. Permanent tables give the appropriate increments and corrections to the tabulated hourly values of GHA and Dec. for the minutes and seconds of UT (GMT).

56ᵐ INCREMENTS AND CORRECTIONS **57ᵐ**

56ᵐ	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	14 00·0	14 02·3	13 21·7	0·0	0·0	6·0	5·7	12·0	11·3
01	14 00·3	14 02·6	13 22·0	0·1	0·1	6·1	5·7	12·1	11·4
02	14 00·5	14 02·8	13 22·2	0·2	0·2	6·2	5·8	12·2	11·5
03	14 00·8	14 03·1	13 22·4	0·3	0·3	6·3	5·9	12·3	11·6
04	14 01·0	14 03·3	13 22·7	0·4	0·4	6·4	6·0	12·4	11·7
55	14 13·8	14 16·1	13 34·9	5·5	5·2	11·5	10·8	17·5	16·5
56	14 14·0	14 16·3	13 35·1	5·6	5·3	11·6	10·9	17·6	16·6
57	14 14·3	14 16·6	13 35·3	5·7	5·4	11·7	11·0	17·7	16·7
58	14 14·5	14 16·8	13 35·6	5·8	5·5	11·8	11·1	17·8	16·8
59	14 14·8	14 17·1	13 35·8	5·9	5·6	11·9	11·2	17·9	16·9
60	14 15·0	14 17·3	13 36·1	6·0	5·7	12·0	11·3	18·0	17·0

57ᵐ	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	14 15·0	14 17·3	13 36·1	0·0	0·0	6·0	5·8	12·0	11·5
01	14 15·3	14 17·6	13 36·3	0·1	0·1	6·1	5·8	12·1	11·6
02	14 15·5	14 17·8	13 36·5	0·2	0·2	6·2	5·9	12·2	11·7
03	14 15·8	14 18·1	13 36·8	0·3	0·3	6·3	6·0	12·3	11·8
04	14 16·0	14 18·3	13 37·0	0·4	0·4	6·4	6·1	12·4	11·9
55	14 28·8	14 31·1	13 49·2	5·5	5·3	11·5	11·0	17·5	16·8
56	14 29·0	14 31·4	13 49·4	5·6	5·4	11·6	11·1	17·6	16·9
57	14 29·3	14 31·6	13 49·7	5·7	5·5	11·7	11·2	17·7	17·0
58	14 29·5	14 31·9	13 49·9	5·8	5·6	11·8	11·3	17·8	17·1
59	14 29·8	14 32·1	13 50·1	5·9	5·7	11·9	11·4	17·9	17·2
60	14 30·0	14 32·4	13 50·4	6·0	5·8	12·0	11·5	18·0	17·3

xxx

Main Data

3- Daily Pages

- The daily pages give the GHA of Aries; the GHA and Dec. of the sun, moon and the four navigational planets, for each hour of GMT.
- For the moon, values "v", "d" is also tabulated for each hour to facilitate the correction of GHA and Dec. to intermediate times; "v", "d" for the sun and planets change so slowly that they are given at the foot of the appropriate columns, once only on the page; "v" is zero for Aries and negligible for the sun, and is omitted.

- The SHA and Dec. of the 57 selected stars, arranged in alphabetical order of proper name, are also given.

4- Increments and Corrections

These tables, printed on tinted paper (pages ii-xxxi) at the back of the Almanac, provide the increments and corrections for minutes and seconds to be applied to the hourly values of GHA and Dec. They consist of sixty tables, one for each minute separated into two parts:

a) Increments to GHA for sun and planets; Aries and Moon for every minute and second;
b) For each minute, corrections to be applied to GHA and Dec. corresponding to the values of "v" and "d" given on the daily pages.

46ᵐ INCREMENTS AND CORRECTIONS 47ᵐ

46ᵐ	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	11 30·0	11 31·9	10 58·6	0·0	0·0	6·0	4·7	12·0	9·3
01	11 30·3	11 32·1	10 58·8	0·1	0·1	6·1	4·7	12·1	9·4
02	11 30·5	11 32·4	10 59·0	0·2	0·2	6·2	4·8	12·2	9·5
03	11 30·8	11 32·6	10 59·3	0·3	0·2	6·3	4·9	12·3	9·5
04	11 31·0	11 32·9	10 59·5	0·4	0·3	6·4	5·0	12·4	9·6
05	11 31·3	11 33·1	10 59·8	0·5	0·4	6·5	5·0	12·5	9·7
06	11 31·5	11 33·4	11 00·0	0·6	0·5	6·6	5·1	12·6	9·8
07	11 31·8	11 33·6	11 00·2	0·7	0·5	6·7	5·2	12·7	9·8
08	11 32·0	11 33·9	11 00·5	0·8	0·6	6·8	5·3	12·8	9·9

47ᵐ	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	11 45·0	11 46·9	11 12·9	0·0	0·0	6·0	4·8	12·0	9·5
01	11 45·3	11 47·2	11 13·1	0·1	0·1	6·1	4·8	12·1	9·6
02	11 45·5	11 47·4	11 13·4	0·2	0·2	6·2	4·9	12·2	9·7
03	11 45·8	11 47·7	11 13·6	0·3	0·2	6·3	5·0	12·3	9·7
04	11 46·0	11 47·9	11 13·8	0·4	0·3	6·4	5·1	12·4	9·8
05	11 46·3	11 48·2	11 14·1	0·5	0·4	6·5	5·1	12·5	9·9
06	11 46·5	11 48·4	11 14·3	0·6	0·5	6·6	5·2	12·6	10·0
07	11 46·8	11 48·7	11 14·6	0·7	0·6	6·7	5·3	12·7	10·1
08	11 47·0	11 48·9	11 14·8	0·8	0·6	6·8	5·4	12·8	10·1

The increments are based on the following adopted hourly rates of increase of the GHA:

- Sun and Planets; 15° 00̀.0 precisely,
- Aries; 15° 2`.464
- Moon 14° 19`.0

The values of "v" on the daily pages are the excesses of the actual hourly motions over the adopted values; they are generally positive, except for Venus in some cases.

Actual Rate of Change of SHA of Celestial Bodies

Stars	15° 02`.464			Fixed
Sun	15° 00`.0			Fixed
Moon	14° 19`.0	→	14° 43`.5	Variable
Venus	14° 59`.0	→	15° 05`.0	Variable
Mars	15° 00`.0	→	15° 04`.0	Variable
Jupiter & Saturn	15° 02`.0	→	15° 03`.4	Variable

The tabulated hourly values of the sun's GHA have been adjusted to reduce to a minimum the error caused by treating "v" as negligible.

$$\text{Actual Rate of change of G.H.A.} = \text{Theoretical Rate} \begin{Bmatrix} 15^\circ \ for\ planets \\ 14^\circ\ 19`.0\ \ for\ Moon \end{Bmatrix} + v$$

The values of (d) in the daily pages are the hourly differences of the Dec. For the Moon, the true values of (v) and (d) are given for each hour; otherwise mean values are given for three days on the page.

5- Method of Entry

The UT of an observation is expressed as a day and hour, followed by a number of minutes and seconds. The tabular values of GHA and, Dec. and where necessary, the corresponding values of "v" and "d", are taken directly from the daily pages for the day and hour of UT; this hour is always before the time of observation. SHA and Dec. of the selected stars are also taken from the daily pages.

The table of increments and corrections for the minute of UT is then selected. For the GHA, the increment for minutes and seconds is taken from the appropriate column opposite the seconds of UT (GMT).

The v-correction is taken from the second part of the same table opposite the value of "v" as given on the daily pages. Both increment and *v-correction* are to be added to the GHA, except for Venus when "v" is prefixed by a minus sign and the v-correction is to be subtracted.

For the Dec. there is no increment, but a *d-correction* is applied in the same way as the v-correction; “d" is given without sign on the daily pages and the sign of the correction is to be supplied by inspection of the Dec column. In many cases the correction may be applied mentally.

1990 MAY 4, 5, 6 (FRI., SAT., SUN.)

	UT (GMT) d h	ARIES G.H.A.	VENUS −4.1 G.H.A.	VENUS Dec.	MARS +0.8 G.H.A.	MARS Dec.	JUPITER −2.0 G.H.A.	JUPITER Dec.	SATURN +0.5 G.H.A.	SATURN Dec.	STARS Name	S.H.A.	Dec.
	4 00	221 37.3	221 15.4	S 1 17.5	239 41.3	S 9 23.4	123 29.8	N23 21.5	284 21.3	S20 54.5	Acamar	315 31.8	S40 20.5
	01	236 39.8	236 15.3	16.5	254 42.0	22.7	138 31.8	21.5	299 23.8	54.5	Achernar	335 39.9	S57 17.0
	02	251 42.2	251 15.1	15.5	269 42.7	22.1	153 33.8	21.5	314 26.2	54.5	Acrux	173 28.6	S63 03.1
	03	266 44.7	266 15.0	·· 14.5	284 43.4	·· 21.4	168 35.8	·· 21.5	329 28.7	·· 54.5	Adhara	255 26.4	S28 57.6
	04	281 47.1	281 14.8	13.5	299 44.1	20.7	183 37.8	21.4	344 31.2	54.5	Aldebaran	291 09.6	N16 29.5
	05	296 49.6	296 14.7	12.5	314 44.8	20.0	198 39.8	21.4	359 33.6	54.5			
	06	311 52.1	311 14.5	S 1 11.5	329 45.5	S 9 19.3	213 41.8	N23 21.4	14 36.1	S20 54.5	Alioth	166 35.1	N56 00.7
	07	326 54.5	326 14.3	10.5	344 46.2	18.7	228 43.8	21.4	29 38.6	54.5	Alkaid	153 11.9	N49 21.6
	08	341 57.0	341 14.2	09.5	359 46.9	18.0	243 45.8	21.4	44 41.0	54.5	Al Na'ir	28 05.4	S47 00.3
F	09	356 59.5	356 14.0	·· 08.5	14 47.6	·· 17.3	258 47.8	·· 21.3	59 43.5	·· 54.5	Alnilam	276 04.2	S 1 12.4
R	10	12 01.9	11 13.9	07.5	29 48.3	16.6	273 49.7	21.3	74 45.9	54.5	Alphard	218 13.1	S 8 37.1
I	11	27 04.4	26 13.7	06.5	44 49.0	15.9	288 51.7	21.3	89 48.4	54.5			
D	12	42 06.9	41 13.6	S 1 05.5	59 49.7	S 9 15.3	303 53.7	N23 21.3	104 50.9	S20 54.5	Alphecca	126 25.3	N26 44.6
A	13	57 09.3	56 13.4	04.5	74 50.4	14.6	318 55.7	21.2	119 53.3	54.5	Alpheratz	358 01.8	N29 02.1
Y	14	72 11.8	71 13.3	03.5	89 51.1	13.9	333 57.7	21.2	134 55.8	54.5	Altair	62 25.0	N 8 50.3
	15	87 14.3	86 13.1	·· 02.5	104 51.9	·· 13.2	348 59.7	·· 21.2	149 58.2	·· 54.5	Ankaa	353 32.9	S42 21.3
	16	102 16.7	101 13.0	01.5	119 52.6	12.5	4 01.7	21.2	165 00.7	54.5	Antares	112 47.3	S26 24.8
	17	117 19.2	116 12.8	1 00.5	134 53.3	11.9	19 03.7	21.2	180 03.2	54.5			
	18	132 21.6	131 12.6	S 0 59.5	149 54.0	S 9 11.2	34 05.7	N23 21.1	195 05.6	S20 54.5	Arcturus	146 11.2	N19 13.8
	19	147 24.1	146 12.5	58.5	164 54.7	10.5	49 07.7	21.1	210 08.1	54.5	Atria	108 04.3	S69 00.7
	20	162 26.6	161 12.3	57.5	179 55.4	09.8	64 09.7	21.1	225 10.6	54.5	Avior	234 25.4	S59 29.0
	21	177 29.0	176 12.2	·· 56.5	194 56.1	·· 09.1	79 11.6	·· 21.1	240 13.0	·· 54.5	Bellatrix	278 50.9	N 6 20.5
	22	192 31.5	191 12.0	55.5	209 56.8	08.5	94 13.6	21.1	255 15.5	54.5	Betelgeuse	271 20.3	N 7 24.4
	23	207 34.0	206 11.9	54.5	224 57.5	07.8	109 15.6	21.0	270 17.9	54.5			
	5 00	222 36.4	221 11.7	S 0 53.5	239 58.2	S 9 07.1	124 17.6	N23 21.0	285 20.4	S20 54.5	Canopus	264 04.2	S52 41.6
	01	237 38.9	236 11.6	52.5	254 58.9	06.4	139 19.6	21.0	300 22.9	54.5	Capella	281 00.5	N45 59.5
	02	252 41.4	251 11.4	51.5	269 59.6	05.7	154 21.6	21.0	315 25.3	54.5	Deneb	49 43.4	N45 14.4
	03	267 43.8	266 11.2	·· 50.5	285 00.3	·· 05.1	169 23.6	·· 20.9	330 27.8	·· 54.5	Denebola	182 51.1	N14 37.5
	04	282 46.3	281 11.1	49.5	300 01.0	04.4	184 25.6	20.9	345 30.3	54.5	Diphda	349 13.5	S18 02.3
	05	297 48.8	296 10.9	48.5	315 01.7	03.7	199 27.6	20.9	0 32.7	54.5			
	06	312 51.2	311 10.8	S 0 47.5	330 02.5	S 9 03.0	214 29.5	N23 20.9	15 35.2	S20 54.5	Dubhe	194 12.2	N61 48.3
	07	327 53.7	326 10.6	46.5	345 03.2	02.3	229 31.5	20.9	30 37.7	54.5	Elnath	278 34.9	N28 36.1
S	08	342 56.1	341 10.5	45.5	0 03.9	01.6	244 33.5	20.8	45 40.1	54.5	Eltanin	90 53.8	N51 29.1
A	09	357 58.6	356 10.3	·· 44.5	15 04.6	·· 01.0	259 35.5	·· 20.8	60 42.6	·· 54.5	Enif	34 04.2	N 9 49.7
T	10	13 01.1	11 10.1	43.5	30 05.3	9 00.3	274 37.5	20.8	75 45.1	54.5	Fomalhaut	15 43.1	S29 40.3
U	11	28 03.5	26 10.0	42.5	45 06.0	8 59.6	289 39.5	20.8	90 47.5	54.5			
R	12	43 06.0	41 09.8	S 0 41.5	60 06.7	S 8 58.9	304 41.5	N23 20.8	105 50.0	S20 54.5	Gacrux	172 20.1	S57 03.9
D	13	58 08.5	56 09.7	40.5	75 07.4	58.2	319 43.5	20.7	120 52.5	54.6	Gienah	176 10.0	S17 29.5
A	14	73 10.9	71 09.5	39.5	90 08.1	57.5	334 45.4	20.7	135 54.9	54.6	Hadar	149 12.2	S60 19.9
Y	15	88 13.4	86 09.4	·· 38.5	105 08.8	·· 56.9	349 47.4	·· 20.7	150 57.4	·· 54.6	Hamal	328 20.8	N23 25.0
	16	103 15.9	101 09.2	37.5	120 09.5	56.2	4 49.4	20.7	165 59.8	54.6	Kaus Aust.	84 06.5	S34 23.4
	17	118 18.3	116 09.0	36.5	135 10.2	55.5	19 51.4	20.6	181 02.3	54.6			
	18	133 20.8	131 08.9	S 0 35.5	150 11.0	S 8 54.8	34 53.4	N23 20.6	196 04.8	S20 54.6	Kochab	137 17.7	N74 11.6
	19	148 23.2	146 08.7	34.5	165 11.7	54.1	49 55.4	20.6	211 07.3	54.6	Markab	13 55.8	N15 09.1
	20	163 25.7	161 08.6	33.4	180 12.4	53.4	64 57.4	20.6	226 09.7	54.6	Menkar	314 33.5	N 4 03.2
	21	178 28.2	176 08.4	·· 32.4	195 13.1	·· 52.8	79 59.3	·· 20.6	241 12.2	·· 54.6	Menkent	148 27.8	S36 19.6
	22	193 30.6	191 08.2	31.4	210 13.8	52.1	95 01.3	20.5	256 14.7	54.6	Miaplacidus	221 43.6	S69 41.0
	23	208 33.1	206 08.1	30.4	225 14.5	51.4	110 03.3	20.5	271 17.1	54.6			
	6 00	223 35.6	221 07.9	S 0 29.4	240 15.2	S 8 50.7	125 05.3	N23 20.5	286 19.6	S20 54.6	Mirfak	309 05.9	N49 49.7
	01	238 38.0	236 07.8	28.4	255 15.9	50.0	140 07.3	20.5	301 22.1	54.6	Nunki	76 19.6	S26 18.6
	02	253 40.5	251 07.6	27.4	270 16.6	49.3	155 09.3	20.4	316 24.5	54.6	Peacock	53 46.2	S56 45.8
	03	268 43.0	266 07.5	·· 26.4	285 17.3	·· 48.7	170 11.3	·· 20.4	331 27.0	·· 54.6	Pollux	243 49.0	N28 03.1
	04	283 45.4	281 07.3	25.4	300 18.1	48.0	185 13.2	20.4	346 29.5	54.6	Procyon	245 18.0	N 5 15.0
	05	298 47.9	296 07.1	24.4	315 18.8	47.3	200 15.2	20.4	1 31.9	54.6			
	06	313 50.4	311 07.0	S 0 23.4	330 19.5	S 8 46.6	215 17.2	N23 20.3	16 34.4	S20 54.6	Rasalhague	96 22.3	N12 33.7
	07	328 52.8	326 06.8	22.4	345 20.2	45.9	230 19.2	20.3	31 36.9	54.6	Regulus	208 01.8	N12 00.8
	08	343 55.3	341 06.7	21.3	0 20.9	45.2	245 21.2	20.3	46 39.3	54.6	Rigel	281 29.0	S 8 12.7
S	09	358 57.7	356 06.5	·· 20.3	15 21.6	·· 44.6	260 23.2	·· 20.3	61 41.8	·· 54.6	Rigil Kent.	140 15.0	S60 47.9
U	10	14 00.2	11 06.3	19.3	30 22.3	43.9	275 25.1	20.3	76 44.3	54.6	Sabik	102 32.2	S15 43.0
N	11	29 02.7	26 06.2	18.3	45 23.0	43.2	290 27.1	20.2	91 46.7	54.6			
D	12	44 05.1	41 06.0	S 0 17.3	60 23.7	S 8 42.5	305 29.1	N23 20.2	106 49.2	S20 54.6	Schedar	350 01.1	N56 28.9
A	13	59 07.6	56 05.9	16.3	75 24.4	41.8	320 31.1	20.2	121 51.7	54.6	Shaula	96 45.2	S37 05.9
Y	14	74 10.1	71 05.7	15.3	90 25.2	41.1	335 33.1	20.2	136 54.2	54.6	Sirius	258 49.2	S16 42.2
	15	89 12.5	86 05.5	·· 14.3	105 25.9	·· 40.4	350 35.1	·· 20.1	151 56.6	·· 54.6	Spica	158 49.3	S11 06.9
	16	104 15.0	101 05.4	13.3	120 26.6	39.8	5 37.0	20.1	166 59.1	54.6	Suhail	223 05.3	S43 23.9
	17	119 17.5	116 05.2	12.3	135 27.3	39.1	20 39.0	20.1	182 01.6	54.7			
	18	134 19.9	131 05.0	S 0 11.2	150 28.0	S 8 38.4	35 41.0	N23 20.1	197 04.0	S20 54.7	Vega	80 50.5	N38 46.1
	19	149 22.4	146 04.9	10.2	165 28.7	37.7	50 43.0	20.1	212 06.5	54.7	Zuben'ubi	137 24.4	S16 00.4
	20	164 24.9	161 04.7	09.2	180 29.4	37.0	65 45.0	20.0	227 09.0	54.7			
	21	179 27.3	176 04.6	·· 08.2	195 30.1	·· 36.3	80 46.9	·· 20.0	242 11.5	·· 54.7			
	22	194 29.8	191 04.4	07.2	210 30.9	35.6	95 48.9	20.0	257 13.9	54.7			
	23	209 32.2	206 04.2	06.2	225 31.6	34.9	110 50.9	20.0	272 16.4	54.7			
	Mer. Pass.	9 08.1 (h m)	v −0.2	d 1.0	v 0.7	d 0.7	v 2.0	d 0.0	v 2.5	d 0.0			

	S.H.A.	Mer. Pass.
Venus	358 35.3	9 15
Mars	17 21.8	8 00
Jupiter	261 41.2	15 41
Saturn	62 44.0	4 58

Solved Example (1)

Given:

- UT (GMT) 20h 22m 11s Jun. 24th; 1990.
- D.R. Longitude 141º 22`.3 E

Calculate: L.H.A. & Dec of the Star ***Antares.***

Solution

126 — 1990 JUNE 24, 25, 26 (SUN., MON., TUES.)

UT (GMT)	ARIES	VENUS −3.9		MARS +0.3		JUPITER −1.8		SATURN +0.2		STARS		
d h	G.H.A. ° ′	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′	Name	S.H.A. ° ′	Dec. ° ′
24 00	271 53.4	214 54.6	N18 11.2	255 20.5	N 4 50.9	162 37.7	N22 27.6	336 33.1	S21 17.6	Acamar	315 31.6	S40 20.3
01	286 55.8	229 54.0	11.9	270 21.4	51.5	177 39.6	27.6	351 35.7	17.6	Achernar	335 39.5	S57 16.7
02	301 58.3	244 53.5	12.7	285 22.2	52.2	192 41.4	27.5	6 38.3	17.7	Acrux	173 28.9	S63 03.2
03	317 00.8	259 52.9	· · 13.4	300 23.0	· · 52.8	207 43.3	· · 27.4	21 41.0	· · 17.7	Adhara	255 26.5	S28 57.5
04	332 03.2	274 52.3	14.1	315 23.8	53.5	222 45.2	27.4	36 43.6	17.7	Aldebaran	291 09.5	N16 29.5
05	347 05.7	289 51.8	14.8	330 24.6	54.2	237 47.1	27.3	51 46.3	17.8			
06	2 08.2	304 51.2	N18 15.5	345 25.5	N 4 54.8	252 48.9	N22 27.2	66 48.9	S21 17.8	Alioth	166 35.4	N56 00.9
07	17 10.6	319 50.7	16.2	0 26.3	55.5	267 50.8	27.1	81 51.5	17.8	Alkaid	153 12.0	N49 21.8
08	32 13.1	334 50.1	16.9	15 27.1	56.2	282 52.7	27.1	96 54.2	17.9	Al Na'ir	28 04.9	S47 00.2
S 09	47 15.6	349 49.5	· · 17.6	30 27.9	· · 56.8	297 54.5	· · 27.0	111 56.8	· · 17.9	Alnilam	276 04.2	S 1 12.3
U 10	62 18.0	4 49.0	18.3	45 28.7	57.5	312 56.4	26.9	126 59.5	17.9	Alphard	218 13.2	S 8 37.1
N 11	77 20.5	19 48.4	19.0	60 29.6	58.2	327 58.3	26.9	142 02.1	17.9			
D 12	92 22.9	34 47.8	N18 19.7	75 30.4	N 4 58.8	343 00.2	N22 26.8	157 04.7	S21 18.0	Alphecca	126 25.2	N26 44.8
A 13	107 25.4	49 47.3	20.4	90 31.2	4 59.5	358 02.0	26.7	172 07.4	18.0	Alpheratz	358 01.4	N29 02.2
Y 14	122 27.9	64 46.7	21.1	105 32.0	5 00.2	13 03.9	26.7	187 10.0	18.0	Altair	62 24.7	N 8 50.5
15	137 30.3	79 46.2	· · 21.8	120 32.8	· · 00.8	28 05.8	· · 26.6	202 12.7	· · 18.1	Ankaa	353 32.5	S42 21.1
16	152 32.8	94 45.6	22.5	135 33.7	01.5	43 07.6	26.5	217 15.3	18.1	Antares	112 47.1	S26 24.9
17	167 35.3	109 45.0	23.2	150 34.5	02.1	58 09.5	26.5	232 17.9	18.1			
18	182 37.7	124 44.5	N18 23.9	165 35.3	N 5 02.8	73 11.4	N22 26.4	247 20.6	S21 18.2	Arcturus	146 11.2	N19 13.9
19	197 40.2	139 43.9	24.6	180 36.1	03.5	88 13.3	26.3	262 23.2	18.2	Atria	108 04.0	S69 00.9
20	212 42.7	154 43.3	25.3	195 36.9	04.1	103 15.1	26.2	277 25.9	18.2	Avior	234 25.8	S59 28.9
21	227 45.1	169 42.8	· · 26.0	210 37.8	· · 04.8	118 17.0	· · 26.2	292 28.5	· · 18.3	Bellatrix	278 50.8	N 6 20.6
22	242 47.6	184 42.2	26.7	225 38.6	05.5	133 18.9	26.1	307 31.1	18.3	Betelgeuse	271 20.3	N 7 24.4
23	257 50.0	199 41.6	27.3	240 39.4	06.1	148 20.7	26.0	322 33.8	18.3			
25 00	272 52.5	214 41.1	N18 28.0	255 40.2	N 5 06.8	163 22.6	N22 26.0	337 36.4	S21 18.4	Canopus	264 04.4	S52 41.3

GHA♈	212 42.7
Incr. ♈	5 33.7
SHA*	112 47.1
GHA*	331 03.5
±Long E/W	141 22.3
LHA*	472 25.8
	<u>112 25.8</u>

Dec. <u>26 24.9 S</u>

Solved Example (2)

Given:

- UT (GMT) 23h 35m 40s Sept. 1st ; 1990.
- D.R. Longitude 46º 33`.5 W

Calculate : L.H.A. & Dec of the Planet ***Venus***

Solution

172 1990 SEPTEMBER 1, 2, 3 (SAT., SUN., MON.)

UT (GMT)	ARIES	VENUS −3.9		MARS −0.4		JUPITER −1.9		SATURN +0.3		STARS		
d h	G.H.A.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.	Name	S.H.A.	Dec.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′		° ′	° ′
1 00	339 54.0	195 01.6	N15 04.8	281 25.9	N18 30.8	214 42.1	N19 50.0	49 13.2	S22 04.6	Acamar	315 31.0	S40 20.1
01	354 56.4	210 01.0	03.9	296 27.1	31.1	229 44.1	49.9	64 15.7	04.6	Achernar	335 38.8	S57 16.6
02	9 58.9	225 00.5	02.9	311 28.2	31.4	244 46.0	49.7	79 18.3	04.6	Acrux	173 29.4	S63 03.0
03	25 01.4	239 59.9	· · 02.0	326 29.4	· · 31.7	259 47.9	· · 49.6	94 20.9	· · 04.7	Adhara	255 26.2	S28 57.2
04	40 03.8	254 59.3	01.1	341 30.6	32.0	274 49.9	49.5	109 23.4	04.7	Aldebaran	291 09.0	N16 29.6
05	55 06.3	269 58.7	15 00.1	356 31.8	32.3	289 51.8	49.4	124 26.0	04.7			
06	70 08.7	284 58.2	N14 59.2	11 33.0	N18 32.6	304 53.8	N19 49.3	139 28.5	S22 04.7	Alioth	166 35.8	N56 00.7
07	85 11.2	299 57.6	58.2	26 34.2	32.9	319 55.7	49.2	154 31.1	04.7	Alkaid	153 12.4	N49 21.7
S 08	100 13.7	314 57.0	57.3	41 35.4	33.2	334 57.7	49.1	169 33.6	04.7	Al Na'ir	28 04.4	S47 00.3
A 09	115 16.1	329 56.4	· · 56.4	56 36.6	· · 33.5	349 59.6	· · 49.0	184 36.2	· · 04.7	Alnilam	276 03.8	S 1 12.2
T 10	130 18.6	344 55.9	55.4	71 37.8	33.7	5 01.5	48.9	199 38.7	04.8	Alphard	218 13.2	S 8 37.0
U 11	145 21.1	359 55.3	54.5	86 39.0	34.0	20 03.5	48.7	214 41.3	04.8			
R 12	160 23.5	14 54.7	N14 53.5	101 40.2	N18 34.3	35 05.4	N19 48.6	229 43.9	S22 04.8	Alphecca	126 25.5	N26 44.9
D 13	175 26.0	29 54.2	52.6	116 41.4	34.6	50 07.4	48.5	244 46.4	04.8	Alpheratz	358 00.9	N29 02.5
A 14	190 28.5	44 53.6	51.7	131 42.6	34.9	65 09.3	48.4	259 49.0	04.8	Altair	62 24.6	N 8 50.7
Y 15	205 30.9	59 53.0	· · 50.7	146 43.8	· · 35.2	80 11.3	· · 48.3	274 51.5	· · 04.8	Ankaa	353 31.9	S42 21.1
16	220 33.4	74 52.4	49.8	161 45.1	35.5	95 13.2	48.2	289 54.1	04.9	Antares	112 47.2	S26 24.9
17	235 35.8	89 51.9	48.8	176 46.3	35.8	110 15.2	48.1	304 56.6	04.9			
18	250 38.3	104 51.3	N14 47.9	191 47.5	N18 36.1	125 17.1	N19 48.0	319 59.2	S22 04.9	Arcturus	146 11.4	N19 13.9
19	265 40.8	119 50.7	46.9	206 48.7	36.3	140 19.0	47.9	335 01.7	04.9	Atria	108 04.5	S69 01.1
20	280 43.2	134 50.2	46.0	221 49.9	36.6	155 21.0	47.8	350 04.3	04.9	Avior	234 25.7	S59 28.5
21	295 45.7	149 49.6	· · 45.0	236 51.1	· · 36.9	170 22.9	· · 47.6	5 06.8	· · 04.9	Bellatrix	278 50.4	N 6 20.7
22	310 48.2	164 49.0	44.1	251 52.3	37.2	185 24.9	47.5	20 09.4	04.9	Betelgeuse	271 19.9	N 7 24.5
23	325 50.6	179 48.5	43.1	266 53.5	37.5	200 26.8	47.4	35 12.0	05.0			
2 00	340 53.1	194 47.9	N14 42.2	281 54.7	N18 37.8	215 28.8	N19 47.3	50 14.5	S22 05.0	Canopus	264 04.0	S52 41.0
D 12	162 21.8	14 27.8	N14 07.5	102 38.6	N18 48.0	36 38.9	N19 43.3	231 46.3	S22 05.5	Schedar	349 59.8	N56 29.2
A 13	177 24.3	29 27.2	06.6	117 39.8	48.3	51 40.9	43.2	246 48.9	05.5	Shaula	96 45.0	S37 06.0
Y 14	192 26.7	44 26.7	05.6	132 41.0	48.5	66 42.8	43.1	261 51.4	05.5	Sirius	258 48.9	S16 41.9
15	207 29.2	59 26.1	· · 04.6	147 42.3	· · 48.8	81 44.8	· · 43.0	276 54.0	· · 05.6	Spica	158 49.5	S11 06.8
16	222 31.7	74 25.6	03.6	162 43.5	49.1	96 46.7	42.9	291 56.5	05.6	Suhail	223 05.5	S43 23.5
17	237 34.1	89 25.0	02.6	177 44.7	49.4	111 48.7	42.8	306 59.0	05.6			
18	252 36.6	104 24.5	N14 01.7	192 46.0	N18 49.7	126 50.6	N19 42.7	322 01.6	S22 05.6	Vega	80 50.3	N38 46.7
19	267 39.1	119 23.9	14 00.7	207 47.2	49.9	141 52.6	42.6	337 04.1	05.6	Zuben'ubi	137 24.5	S16 00.3
20	282 41.5	134 23.4	13 59.7	222 48.4	50.2	156 54.5	42.5	352 06.7	05.6		S.H.A.	Mer. Pass.
21	297 44.0	149 22.8	· · 58.7	237 49.7	· · 50.5	171 56.5	· · 42.4	7 09.2	· · 05.6		° ′	h m
22	312 46.4	164 22.3	57.7	252 50.9	50.8	186 58.4	42.2	22 11.8	05.7	Venus	213 54.8	11 01
23	327 48.9	179 21.7	56.8	267 52.1	51.0	202 00.4	42.1	37 14.3	05.7	Mars	301 01.6	5 12
										Jupiter	234 35.7	9 37
Mer. Pass.	h m 1 16.3	v −0.6	d 1.0	v 1.2	d 0.3	v 1.9	d 0.1	v 2.6	d 0.0	Saturn	69 21.4	20 36

GHA	179 48.5	Dec.	14 43.1 N
Incr.	8 55.0	d. Coor^n	00.6
v. Coor^n	(-)0 0.4	C. Dec.	14 42.5 N
GHA	188 43.1		
±Long E/W	46 33.5	v - 0.6	
LHA	142 09.6	d - 1.0	

Solved Example (3)

Given:

- UT (GMT) 00h 44m 53s May. 13th 1990.
- D.R. Longitude 143º 00`.0 E

Calculate : L.H.A. & Dec of the ***Sun.***

Solution

1990 MAY 13, 14, 15 (SUN., MON., TUES.) 99

UT (GMT)	SUN G.H.A.	SUN Dec.	MOON G.H.A.	MOON v	MOON Dec.	MOON d	MOON H.P.
d h	° ′	° ′	° ′	′	° ′	′	′
13 00	180 55.5	N18 16.0	324 02.4	9.9	S26 52.2	1.3	54.4
01	195 55.5	16.6	338 31.3	9.9	26 50.9	1.3	54.4
02	210 55.5	17.2	353 00.2	10.0	26 49.6	1.5	54.4
03	225 55.5	. . 17.8	7 29.2	9.9	26 48.1	1.6	54.4
04	240 55.5	18.4	21 58.1	9.9	26 46.5	1.8	54.4
05	255 55.5	19.1	36 27.0	10.0	26 44.7	1.9	54.4
06	270 55.5	N18 19.7	50 56.0	9.9	S26 42.8	2.0	54.4
07	285 55.6	20.3	65 24.9	10.0	26 40.8	2.1	54.5
08	300 55.6	20.9	79 53.9	9.9	26 38.7	2.3	54.5
S 09	315 55.6	. . 21.5	94 22.8	10.0	26 36.4	2.5	54.5
U 10	330 55.6	22.2	108 51.8	10.0	26 33.9	2.5	54.5
20	120 55.5	57.0	229 54.4	11.7	20 38.5	9.5	55.7
21	135 55.5	. . 57.6	244 05.1	11.8	20 29.0	9.7	55.7
22	150 55.5	58.2	258 35.9	11.8	20 19.3	9.8	55.7
23	165 55.5	58.8	273 06.7	11.8	20 09.5	9.8	55.7
	S.D. 15.8	*d* 0.6	S.D. 14.9		15.0		15.1

Lat.	Twilight Naut.	Twilight Civil	Sunrise	Moonrise 13	Moonrise 14	Moonrise 15	Moonrise 16
°	h m	h m	h m	h m	h m	h m	h m
N 72	▭	▭	▭	▬	▬	▬	▬
N 70	////	////	00 57	▬	▬	▬	04 00
68	////	////	01 54	▬	▬	▬	03 03
66	////	////	02 27	▬	▬	03 04	02 28
64	////	01 17	02 51	▬	02 40	02 14	02 03
62	////	01 57	03 10	01 18	01 37	01 43	01 44
60	////	02 23	03 25	00 32	01 03	01 19	01 27
N 58	01 09	02 44	03 38	00 02	00 38	01 00	01 14
56	01 45	03 00	03 50	24 18	00 18	00 44	01 02
54	02 10	03 14	03 59	24 01	00 01	00 30	00 51
52	02 29	03 26	04 08	23 47	24 18	00 18	00 42
50	02 45	03 37	04 16	23 34	24 08	00 08	00 34

Day	Eqn. of Time 00h	Eqn. of Time 12h	Mer. Pass.	Mer. Pass. Upper	Mer. Pass. Lower	Age	Phase
	m s	m s	h m	h m	h m	d	
13	03 42	03 42	11 56	02 29	14 55	18	◑
14	03 43	03 43	11 56	03 20	15 46	19	
15	03 43	03 42	11 56	04 10	16 35	20	

G.H.A.	180 55.5	Dec.	18 16.0 N
Incr.	11 13.3	d Correc.(+)	0.4
G.H.A.	192 08.8	C. Dec.	18 16.4 N
±Long E/W	143 00.0		
L.H.A.	335 08.8	d = +0.6	

Solved Example (4)

Given:

- UT (GMT) 14h 05m 04s Oct. 11th 1990.
- D.R. Longitude 49º 51`.3 W

Calculate : L.H.A. & Dec of the ***Moon***

Solution

1990 OCTOBER 10, 11, 12 (WED., THURS., FRI.)

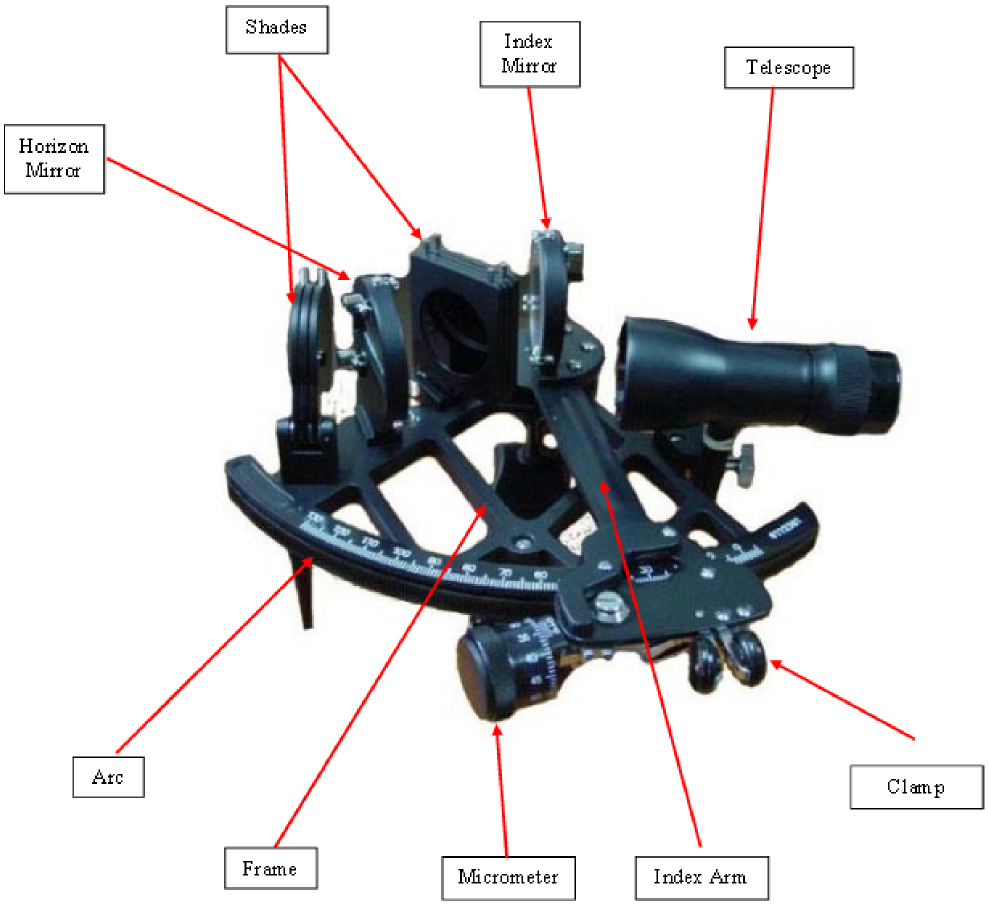
UT (GMT)		SUN		MOON					Lat.	Twilight		Sunrise	10
		G.H.A.	Dec.	G.H.A.	v	Dec.	d	H.P.		Naut.	Civil		
d	h	° ′	° ′	° ′	′	° ′	′	′	°	h m	h m	h m	h m
									N 72	04 36	05 55	07 03	▭
10	00	183 12.1	S 6 27.7	286 41.1	4.1	N26 10.9	3.1	59.4	N 70	04 42	05 53	06 55	▭
	01	198 12.3	28.6	301 04.2	4.1	26 07.8	3.3	59.4	68	04 47	05 51	06 48	▭
	02	213 12.4	29.6	315 27.3	4.2	26 04.5	3.5	59.3	66	04 51	05 50	06 42	▭
	03	228 12.6	. . 30.5	329 50.5	4.2	26 01.0	3.6	59.3	64	04 54	05 49	06 37	19 01
	04	243 12.8	31.4	344 13.7	4.4	25 57.4	3.9	59.3	62	04 57	05 48	06 32	19 45
	05	258 12.9	32.4	358 37.1	4.4	25 53.5	4.0	59.3	60	04 59	05 47	06 29	20 15
	06	273 13.1	S 6 33.3	13 00.5	4.5	N25 49.5	4.1	59.2	N 58	05 00	05 46	06 25	20 37
W	07	288 13.3	34.3	27 24.0	4.5	25 45.4	4.4	59.2	56	05 02	05 45	06 22	20 55
E	08	303 13.4	35.2	41 47.5	4.7	25 41.0	4.5	59.2	54	05 03	05 44	06 20	21 11
D	09	318 13.6	. . 36.2	56 11.2	4.7	25 36.5	4.6	59.2	52	05 04	05 43	06 17	21 24
N	10	333 13.8	37.1	70 34.9	4.8	25 31.9	4.9	59.2	50	05 05	05 43	06 15	21 35
E	11	348 13.9	38.1	84 58.7	4.9	25 27.0	4.9	59.1	45	05 07	05 41	06 10	21 59
S	12	3 14.1	S 6 39.0	99 22.6	4.9	N25 22.1	5.2	59.1	N 40	05 07	05 39	06 06	22 19
D	13	18 14.3	40.0	113 46.5	5.1	25 16.9	5.3	59.1	35	05 08	05 37	06 02	22 35
A	14	[illegible]	[illegible].9	128 10.6	5.1	25 11.6	5.5	59.1	30	05 07	05 35	05 59	22 48
Y	15	48 14.6	. . 41.9	142 34.7	5.3	25 06.1	5.7	59.0	20	05 06	05 31	05 53	23 12
	16	63 14.8	42.8	156 59.0	5.3	25 00.4	5.8	59.0	N 10	05 03	05 27	05 48	23 32
	17	78 14.9	43.8	171 23.3	5.4	24 54.6	5.9	59.0	0	04 59	05 23	05 44	23 51
	18	93 15.1	S 6 44.7	185 47.7	5.5	N24 48.7	6.1	59.0	S 10	04 53	05 17	05 39	24 10
	19	108 15.3	45.7	200 12.2	5.6	24 42.6	6.3	58.9	20	04 45	05 11	05 33	24 30
	20	123 15.4	46.6	214 36.8	5.7	24 36.3	6.4	58.9	30	04 34	05 03	05 27	00 00
	21	138 15.6	. . 47.5	229 01.5	5.8	24 29.9	6.6	58.9	35	04 27	04 58	05 23	00 15
	22	153 15.8	48.5	243 26.3	5.9	24 23.3	6.7	58.9	40	04 19	04 52	05 19	00 33

GHA	128 10.6	Dec.	25 11.6 N
Incr.	1 12.5	d. Coorn	0.5
v. Coorn	0.5	C.Dec.	25 11.1 N
GHA	129 23.6		
±Long E/W	49 51.3	v 5.1	
LHA	79 32.3	d - 5.1	

Marine Sextant

Introduction

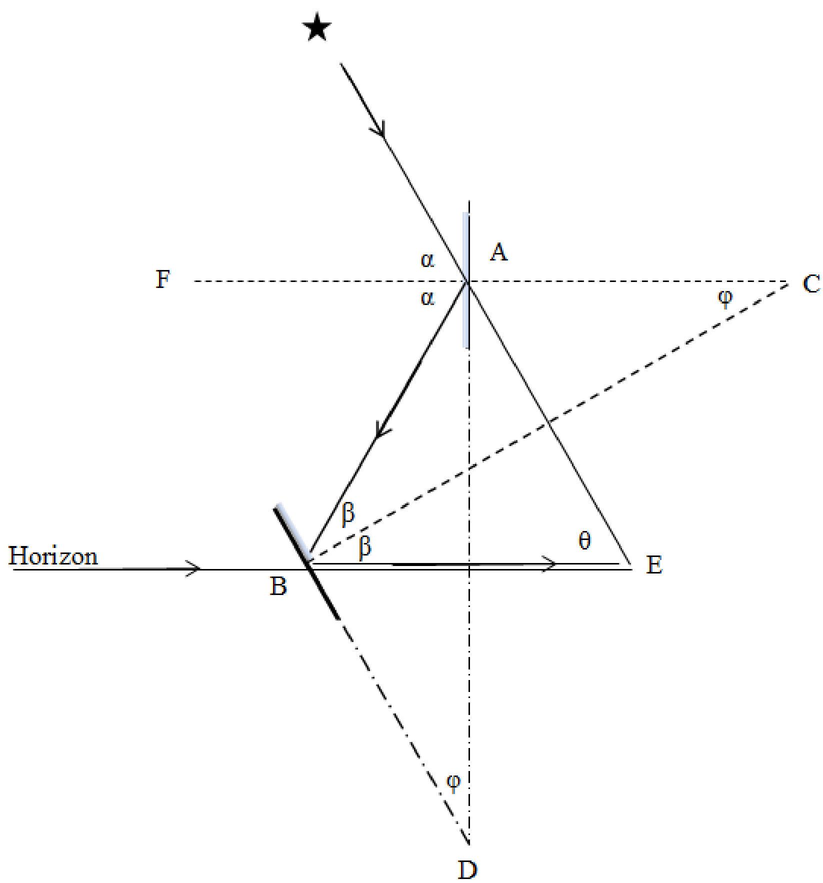
The marine sextant is used by the mariner to observe the altitude of celestial bodies as well as to measure horizontal and vertical angles of terrestrial objects. On the image of a sextant below highlight for the main component features is done.



Optical Principles of a Sextant

The principle of optics involved is stated:

The angle between the first and last directions of a ray of light that has undergone two reflections in the same plane is twice the angle that the two reflecting surfaces make with each other.



Assuming:

θ: the angle of altitude;

(*The angle between the first and last directions of a ray of light that has undergone two reflections*)

φ: the angle moved by Index arm on the graduated arc;

(*The angle that the two reflecting surfaces make with each other*)

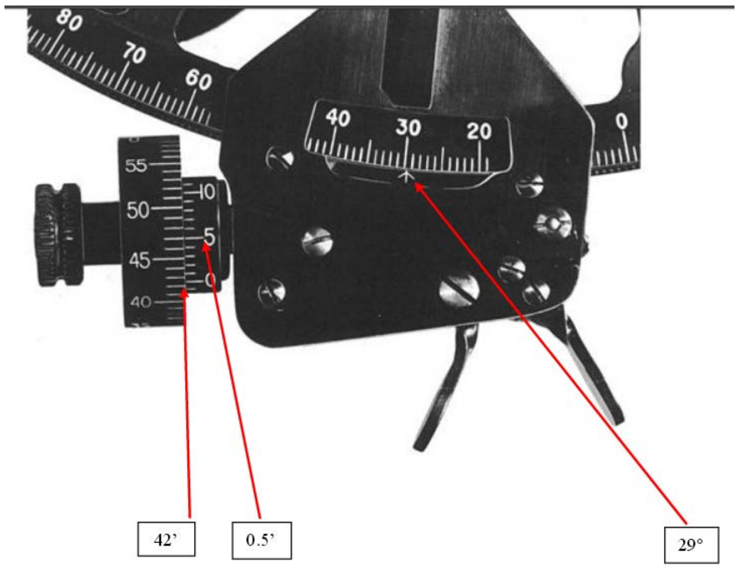
Δ ABC $\rightarrow$ $\alpha = \beta + \varphi$

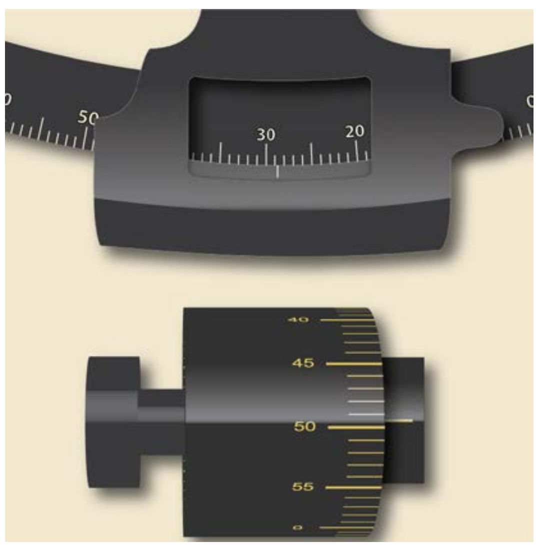
Δ ABE $\rightarrow$ $2\alpha = 2\beta + \theta$

Thus $\theta = 2\varphi$ for this reason:

The angles on the graduated arc are doubled.

Reading Measured Angles





Measured Angle : 28° 49`.5

Instrument error

A good sextant is accompanied by a calibration certificate which reports the "reading errors "along its full graduated scale; otherwise the factory declares that the instrument is free of errors (certifying that the error is less than +/- 9" which is negligible for practical use).

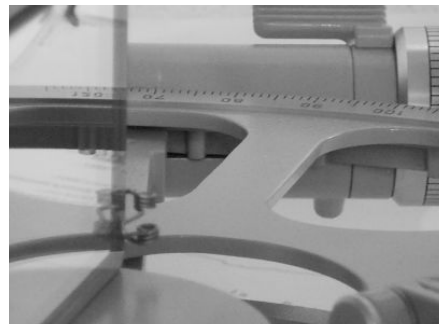
Adjustable errors

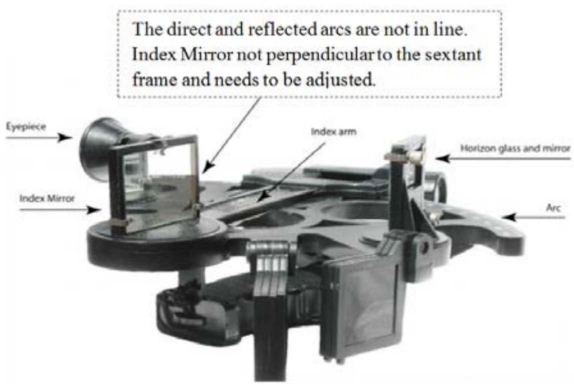
The sequence has to be respected in detecting and removing of errors:

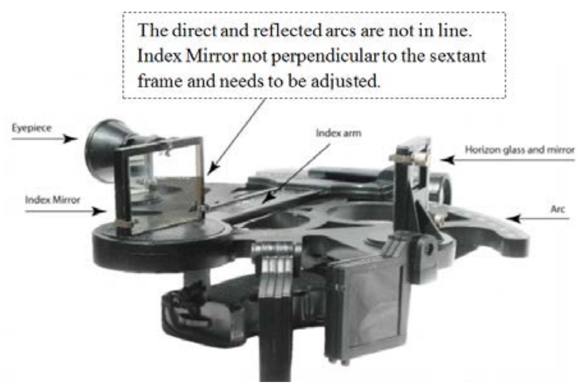
- Perpendicularity Error
- Side Error
- Collimation Error
- Index Error

Perpendicularity Error

This error appears when the index mirror (rectangular mirror) is not perpendicular to the frame (and arc). It is easy to detect it.
Put the sextant on a horizontal plane and move the Index Arm to a position 35°-45° degrees. Look at the index mirror in the direction of arc (graduated scale). We see two images of the scale: the reflected image on the left side, the direct image on the right side. We must see a straight line (the arc with the graduated scale) as in this photo;

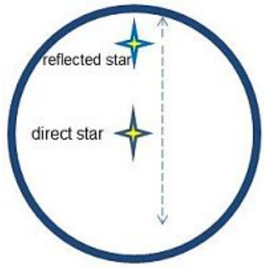






If we see a broken line we remove the error using the adjusting screw on the index mirror:

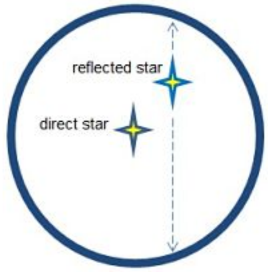
Side Error



This error appears when the horizon mirror (rounded mirror) is not perpendicular to the frame.

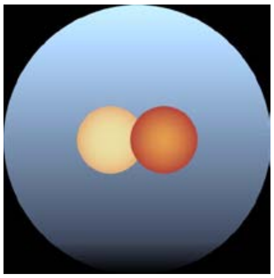
To check the existence of *Side Error*, we use any of the following objects; faint star, sun, light house (at a distance > one nautical mile) or sea horizon.

In case of using a faint star, set the Index Arm to zero degrees, observe the star with the sextant and move the drum (minute scale/micrometer).
The reflected star has to pass alternately below and above the direct star



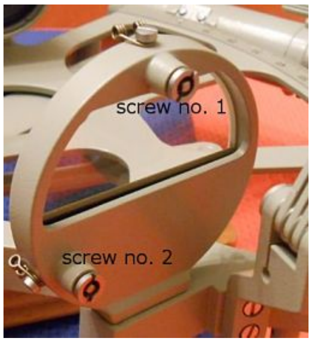
Here the reflected star does not pass on the direct star in the vertical movement; thus the side error exists.

In case of use the sun or far light house, hold the sextant vertically and look directly to the object. If there a side shift of the object, side error exists.
In the figures below side error exists



Reflected Image
Direct Image

In case of use the sea horizon, hold the sextant horizontally and look at the horizon with the telescope: direct horizon and the reflected horizon should be a straight line. In the figure below side error exists



The "side error" must be removed using the adjusting screw on the horizon mirror (screw no. 1):

Collimation Error

"A high quality sextant is not affected by this error "

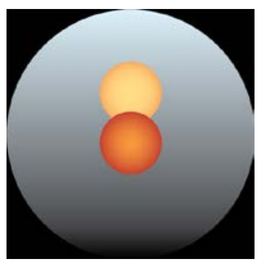
Index error

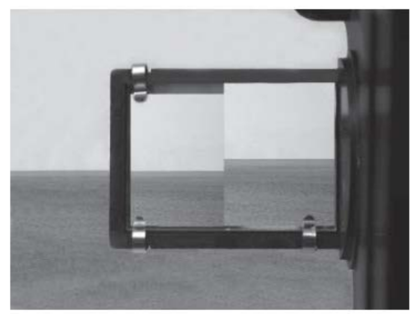
The sextant has an index error if the index mirror and horizon mirror are not parallel when the index arm and the drum with minute scale are set exactly at zero. If the error is more than +/- 3`.0 we have to reduce it.

To check the existence of *Index Error*, we use any of the following objects; faint star, sun, light house (at a distance > one nautical mile) or sea horizon.

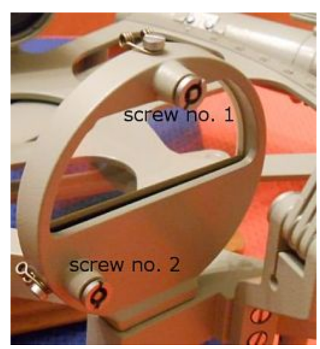
In case of use the sun, far light house or sea horizon; hold the sextant vertically and look directly to the object. If there a vertical shift of the object, index error exists.
In the figures below index error exists.

The "side error" must be removed using the adjusting screw on the horizon mirror (screw no. 1):

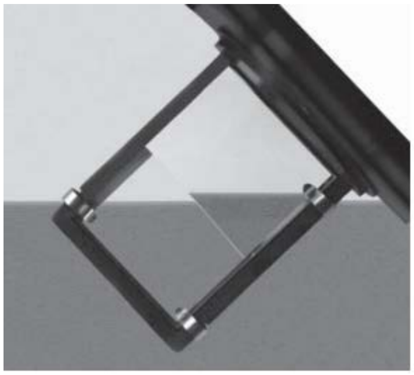


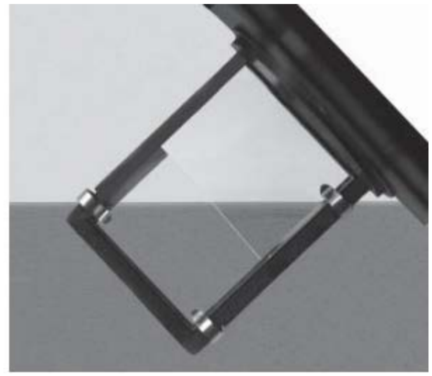


The *Index Error* must be removed using the adjusting screw on the horizon mirror (screw no. 2). Figure (   ).



Practically the side error and the index error are adjusted together. This is done by removing screw no.1then screw no.2 consecutively until the reflected image is completely coincides to the direct image.





To be sure that the two errors were removed incline the sextant to right or left and notices the line of the sea horizon; if there are a shift, side error adjustment must be repeated. See Figure ( ).

Calculation of Index Error

Navigator cannot bring the reflected image in coincidence to the direct image completely, this is because the nature of the human eye.
To calculate the residual error (***Index Error)*** we can use the sun or sea horizon.
In case of use of sea horizon;

- Put the index and micrometer at zero readings.
- Look for the sea horizon and notice the following:
    1. If the there are no cut in the line of the horizon the Index Error is considered nil. Figure (a)
    2. If there is a cut in the line of sea horizon index error is present Figure (b)
- In case of the existence of the error, turn the micrometer slowly until the cut is removed. The reading is the ***Index Error*** and must be less than ±3`.0.

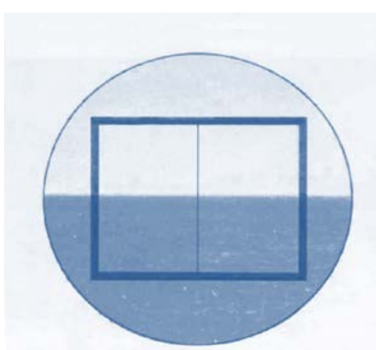


Figure (a)

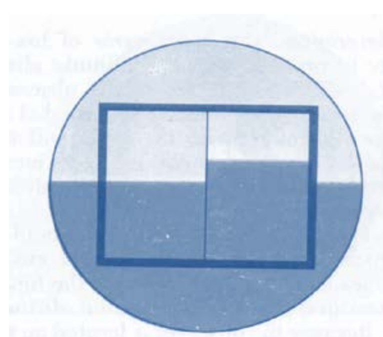
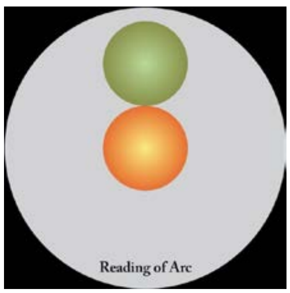
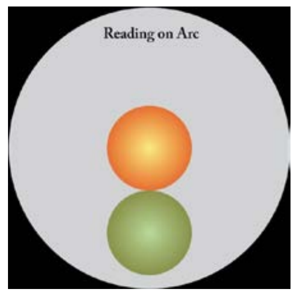


Figure (b)

In case of use the Sun:

- Put the index and micrometer at zero readings.
- Put the suitable shades.
- Adjust the focus of the telescope.
- Look for the sun and :
    1) Turn the micrometer drum until the reflected sun being in touch with the direct sun. Take the reading and note it.
    2) Turn the micrometer drum in the opposite direction until the reflected sun being in touch with the direct sun from the other side. Take the reading and note it.





- The noted readings are <u>on arc</u> and <u>off arc</u>. Apply the following formula to obtain the ***Index Error.***

I.E. = [(Reading off arc - Reading on arc) / 2]

- To be satisfied of the above process apply the following rule to obtain the Semi Diameter (SD) of sun which must be equal to that given in the Nautical Almanac Tables in day of the process.

S.D. = [(Reading off arc + Reading on arc) / 4]

SOLVED EXAMPLE (1)

When Calculating the Index correction of the marine sextant using the Sun; on 29th May ; the following observations were obtained :

1st observation: 32`.0 on the arc.
2nd observation: 31`.2 off the arc.

Calculate the index correction and state its satisfaction.

Answer :

I.C. = $[\frac{31.2-32.0}{2}]$ = - 0`.4

S.D. = $[\frac{31.2+32.0}{4}]$ = 15`.8; agree with the S.D. given the daily page of 29th May in *Nautical. Almanac.*

SO
1. The readings are satisfied.
2. The Index Correction obtained, is recommended.

SOLVED EXAMPLE (2)

When Calculating the Index correction of the marine sextant using the Sun ; on 5th January ; the following observations were obtained :

1st observation: 33`.4 on the arc.
2nd observation: 33`.8 off the arc.

Calculate the index correction and state its satisfaction.

Answer :

I.C. = $\left[\frac{33.8-33.4}{2}\right]$ = + 0`.2

S.D. = $\left[\frac{33.8+33.4}{4}\right]$ = 16`.8 whilst the value given in the *Nautical Almanac* is 16`.3

SO

1. The readings are not satisfied.
2. The process of obtaining the *index correction* must be repeated.

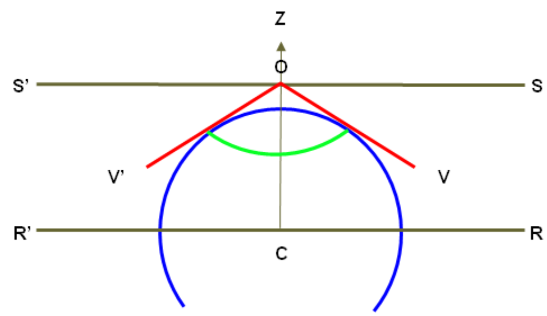
Corrections of Sextant Altitude

The Horizon

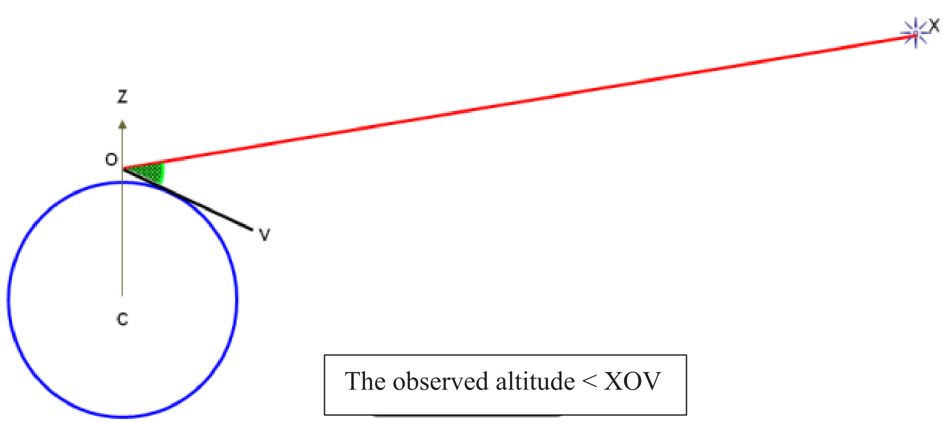
The range of vision in sea is limited by the Curvature of the earth .The vision of an observer at O should be limited by the circle VV', this is the ***Visible Horizon***.

If we imagine a limitless plane passing through the observer's eye at right angle to the earth's radius, passing through the observer, this plane is the ***Sensible Horizon*** SOS'.

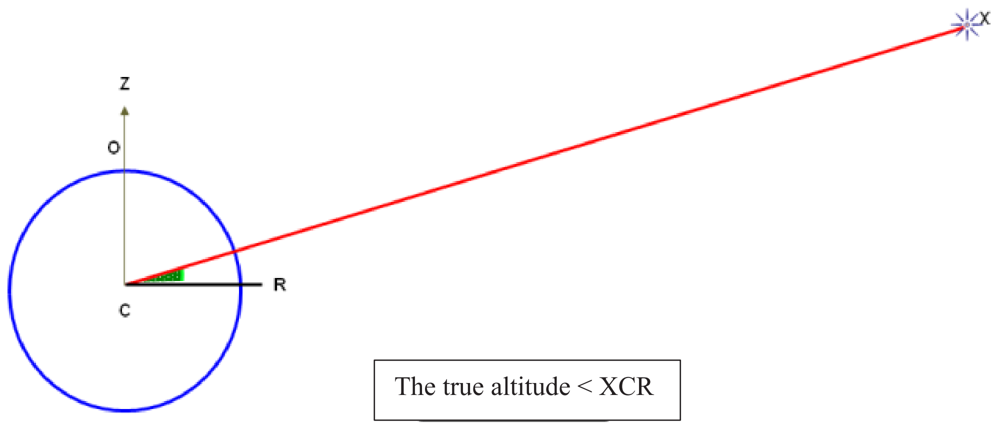
The plane passing through the earth's center parallel to the sensible horizon is the ***Rational Horizon*** RCR'. The rational horizon is a great circle on the celestial sphere.



When the observer takes the sextant altitude of a heavenly body he measures the angle of elevation above the visible horizon. This is the sextant altitude and when corrected for sextant error it is known as the observed altitude XOV.



The position of the body with reference to the visible horizon at the instant of observation has now been determined (***observed altitude***) and it becomes necessary to convert this altitude into a ***true altitude*** which is the angular elevation above the rational horizon XCR.



The true altitude < XCR

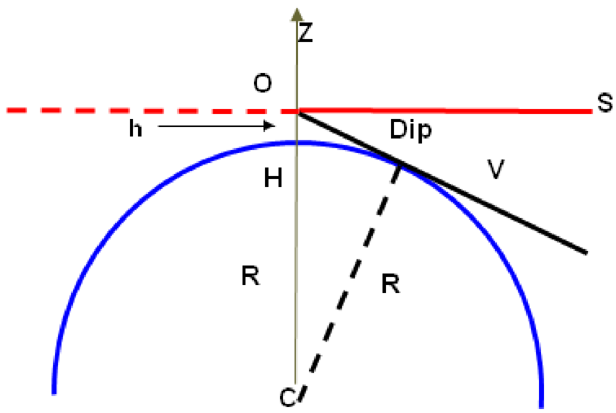
Corrections of the sextant altitude:

The various corrections to be applied to the sextant altitude in order to obtain the true altitude are:

1. **Index error**: to obtain the observed altitude
2. **Dip:** to correct the angular depression of the visible horizon below the sensible horizon.
3. **Refraction:** to allow for the bending of the light rays as they pass through the atmosphere.
4. **Semi–diameter**: to convert the altitude from that of the limb of the body to its center (for the Sun and the Moon).
5. **Parallax:** to convert from sensible horizon to rational horizon and is applied because the observer is at the circumference and not the center of the earth (for the Moon, Venus and Mars).

Angle of Dip:

Dip is the angular depression of the visible horizon below the sensible horizon. Dip is always subtracted and must be applied to any altitude unless an artificial horizon or bubble sextant has been used, both of which indicate the sensible horizon.
The value of the dip can be extracted from the table of Dip given in N.A. tables. This table is arranged as a critical table. In this an interval of height of eye corresponds to a single value of the correction; no interpolation is required.



Z: Zenith point
O: the observer's eye
C: Earth's Center
OH: Height of eye
OC=OH+HC
Or
OC=(h + R)

At a critical entry the upper of the two possible values of the correction is to be taken; for example, a correction of (-4.1`) corresponds to all values of the height of eye from 5.3m to 5.5m inclusive

DIP				
Ht. of Eye	Corrn	Ht. of Eye	Ht. of Eye	Corrn
m		ft.	m	′
4·5		14·9		
	—3·8		24	— 8·6
4·7		15·7		
	—3·9		26	— 9·0
5·0		16·5		
	—4·0		28	— 9·3
5·2		17·4		
	—4·1			
5·5		18·3		
	—4·2		30	— 9·6
5·8		19·1		
	—4·3		32	—10·0
6·1		20·1		

Refraction

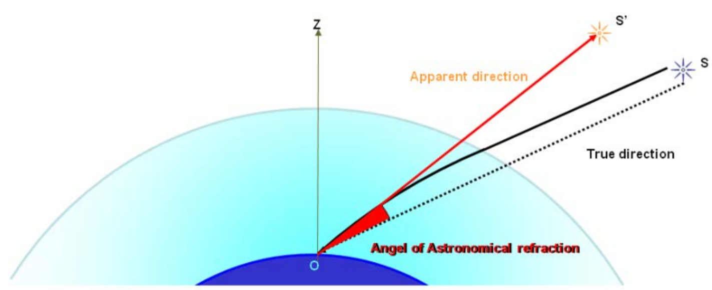
If a ray of light passes through media of different densities, the ray is bent or refracted. The rule in optics states that if a ray of light passes to a denser medium it is refracted towards the normal.

The atmosphere near the earth`s surface is more dense than at great heights because it is compressed by the weight of the upper layers.

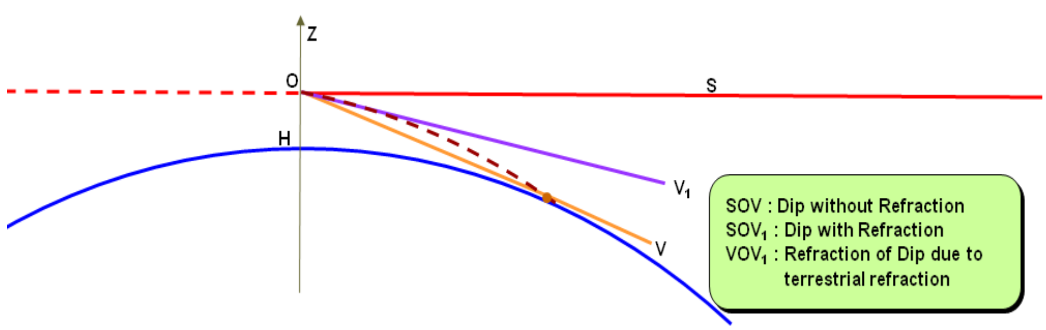
Light rays passing downwards through the atmosphere are successively bent towards the normal and therefore reach the observer at a steeper angle.

The effect of these phenomena is twofold:

1) The apparent direction of the heavenly body is higher than the true direction by an amount called the *astronomical refraction*.



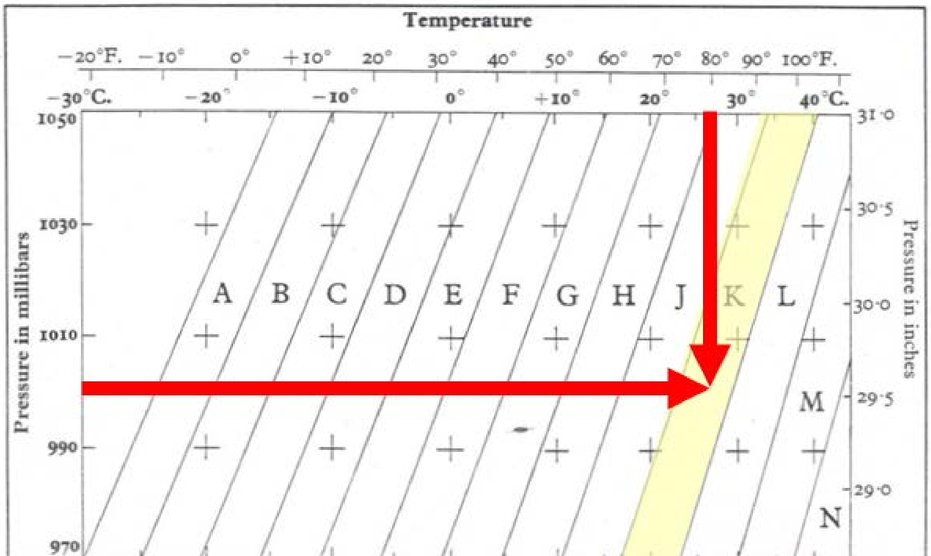
2) The direction of the horizon is usually lifted up, this is called *terrestrial refraction*.



Mean Refraction

It is the value of the astronomical refraction with the barometer 1010 mbs and a 10°C temperature.
There is also a correction table to correct the *mean refraction* for different pressures and temperatures where a special *accuracy* is required.

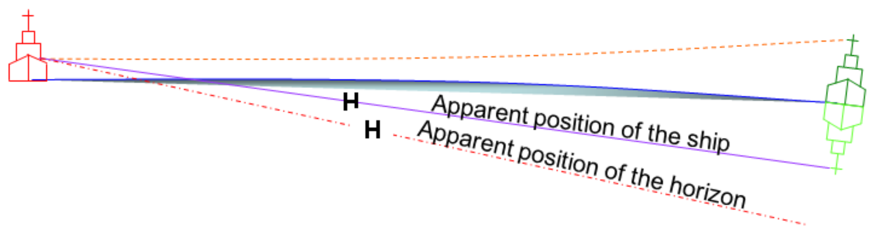
For Atmospheric Pressure 1000 mb
and Air Temperature 27°C
Additional Correction + 0`.3



App. Alt.	A	B	C	D	E	F	G	H	J	K	L	M	N	App. Alt.
° ′	′	′	′	′	′	′	′	′	′	′	′	′	′	° ′
0 00	−6·9	−5·7	−4·6	−3·4	−2·3	−1·1	0·0	+1·1	+2·3	+3·4	+4·6	+5·7	+6·9	0 00
0 30	5·2	4·4	3·5	2·6	1·7	0·9	0·0	0·9	1·7	2·6	3·5	4·4	5·2	0 30
1 00	4·3	3·5	2·8	2·1	1·4	0·7	0·0	0·7	1·4	2·1	2·8	3·5	4·3	1 00
1 30	3·5	2·9	2·4	1·8	1·2	0·6	0·0	0·6	1·2	1·8	2·4	2·9	3·5	1 30
2 00	3·0	2·5	2·0	1·5	1·0	0·5	0·0	0·5	1·0	1·5	2·0	2·5	3·0	2 00
2 30	−2·5	−2·1	−1·6	−1·2	−0·8	−0·4	0·0	+0·4	+0·8	+1·2	+1·6	+2·1	+2·5	2 30
3 00	2·2	1·8	1·5	1·1	0·7	0·4	0·0	0·4	0·7	1·1	1·5	1·8	2·2	3 00
3 30	2·0	1·6	1·3	1·0	0·7	0·3	0·0	0·3	0·7	1·0	1·3	1·6	2·0	3 30
4 00	1·8	1·5	1·2	0·9	0·6	0·3	0·0	0·3	0·6	0·9	1·2	1·5	1·8	4 00
4 30	1·6	1·4	1·1	0·8	0·5	0·3	0·0	0·3	0·5	0·8	1·1	1·4	1·6	4 30
5 00	−1·5	−1·3	−1·0	−0·8	−0·5	−0·2	0·0	+0·2	+0·5	+0·8	+1·0	+1·3	+1·5	5 00
6	1·3	1·1	0·9	0·6	0·4	0·2	0·0	0·2	0·4	0·6	0·9	1·1	1·3	6
7	1·1	0·9	0·7	0·6	0·4	0·2	0·0	0·2	0·4	0·6	0·7	0·9	1·1	7
8	1·0	0·8	0·7	0·5	0·3	0·2	0·0	0·2	0·3	0·5	0·7	0·8	1·0	8
9	0·9	0·7	0·6	0·4	0·3	0·1	0·0	0·1	0·3	0·4	0·6	0·7	0·9	9
10 00	−0·8	−0·7	−0·5	−0·4	−0·3	−0·1	0·0	+0·1	+0·3	+0·4	+0·5	+0·7	+0·8	10 00
12	0·7	0·6	0·5	0·3	0·2	0·1	0·0	0·1	0·2	0·3	0·5	0·6	0·7	12
14	0·6	0·5	0·4	0·3	0·2	0·1	0·0	0·1	0·2	0·3	0·4	0·5	0·6	14
16	0·5	0·4	0·3	0·3	0·2	0·1	0·0	0·1	0·2	0·3	0·3	0·4	0·5	16
18	0·4	0·4	0·3	0·2	0·2	0·1	0·0	0·1	0·2	0·2	0·3	0·4	0·4	18
20 00	−0·4	−0·3	−0·3	−0·2	−0·1	−0·1	0·0	+0·1	+0·1	+0·2	+0·3	+0·3	+0·4	20 00

Abnormal Refraction

The mean value of refraction is calculated for the normal atmosphere conditions where temperature and pressure are considered to fall steadily with increased height.
Actual atmospheric conditions however often differ considerably from this theoretical normal and result in *abnormal* refraction
In fact refraction is the most uncertain factor in the observation and the quantities given in the tables may be in error by as much as 20` or more.



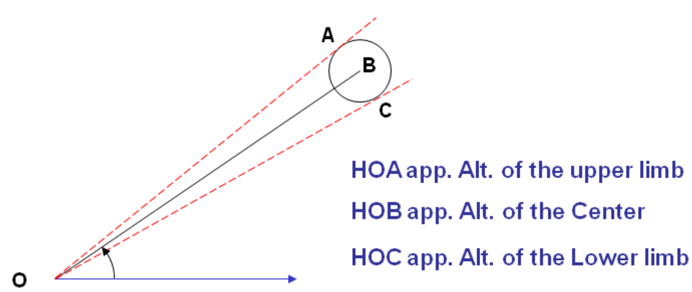
Such abnormal refraction will be liable to occur when the sea is warmer than the air and this frequently happens near land masses, for example in the Red Sea, Arabian (Persian) Gulf, the west Coast of Africa and on the edges of the Gulf stream. The effect of unequal heating give rise to stratification; that is layers of atmosphere of different densities through which the light may suffers abnormal refraction. The optical effects of this are generally termed *mirage*.

The lower portion of the atmosphere is most subject to stratification and this is one reason why observations should generally be taken from the upper bridge.

No general rules for dealing with abnormal refraction are available but whenever it is suspected the results of astronomical observations should be treated *with caution*.

Semi-Diameter

The sun and moon do not appear as points but as bodies with an appreciable diameter.
The altitude of the lower or upper limb (edge) is measured with the sextant and in order to find the altitude of the center, semi-diameter must be added or subtracted, respectively.
The value of the sun and moon's semi diameters are given in the Nautical Almanac for each day.
Semi-diameter must be added to a lower limb observation and subtracted from an upper limb observation.



The value of the Sun's semi diameter varies from 15.75' at the beginning of July when the earth is farthest from the sun (aphelion) to 16.3' in January when it is closest (Perihelion).

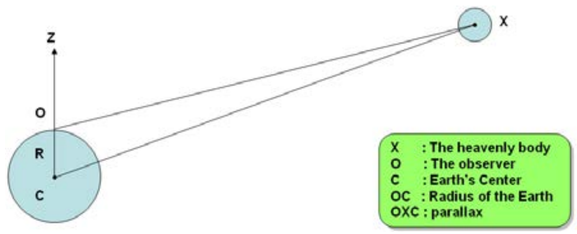
SUN			MOON					
G.H.A.		Dec.	G.H.A.	v	Dec.		d	H.P.
° '		° '	° '	'	°	'	'	'
176 40.1	S 9	38.3	193 46.2	10.7	S15	32.0	13.4	58.2
191 40.2		37.4	208 15.9	10.7	15	18.6	13.6	58.2
206 40.3		36.4	222 45.6	10.8	15	05.0	13.6	58.2
221 40.4		35.5	237 15.4	10.8	14	51.4	13.7	58.3
116 46.7		35.1	100 08.2	11.3	2	08.0	16.7	59.7
131 46.8	. .	34.1	114 38.5	11.3	2	24.7	16.6	59.7
146 46.9		33.2	129 08.8	11.3	2	41.3	16.6	59.8
161 47.1		32.3	143 39.1	11.2	2	57.9	16.7	59.8
S.D. 16.2	d	0.9	S.D.	15.9		16.1		16.2

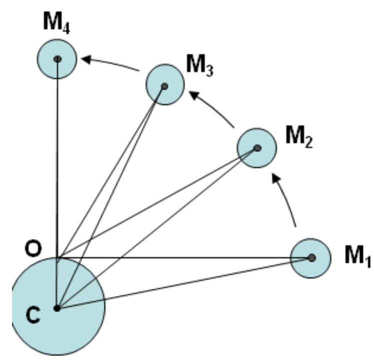
The value of the moon's semi-diameter varies between 14.5' and 17.0'
If the moon is either crescent or gibbous the observer has no choice as to which limb to take since it is only at full moon that both limbs are visible.

Parallax

So far we have considered the case of an observer on the surface of the earth, and have corrected the altitude to the level of the sensible horizon. Since we need the true altitude at the center of the earth above the rational horizon, we must allow for the difference which is called the parallax.

The parallax is therefore the angle subtended at the body by the radius of the earth to the observer's position; and it is show in figure by the angle OXC.

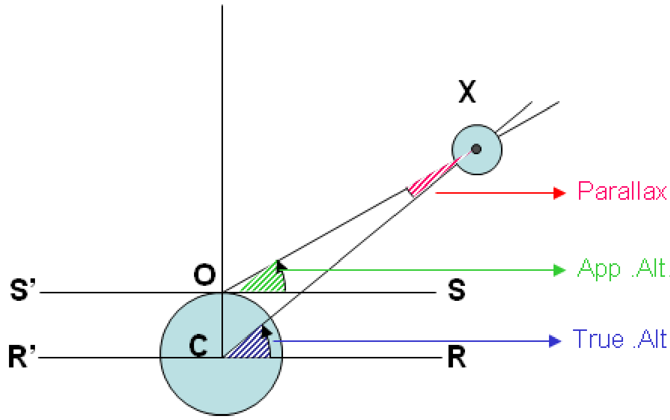




Parallax decreases with increasing Altitude

It is seen also that the true altitude RCX is greater than the apparent altitude by an amount equal to the parallax angle OXC, so that the correction for parallax is always additive.
Referring to the above left figure; it is obvious that the parallax gets less as the body rises above the horizon; and it will be zero a body with an altitude of 90 °.
The maximum value of parallax will therefore be when the body is on the sensible horizon; at M_1 when it is called the horizontal parallax, abbreviated to (H.P.).

Relation between Parallax & Horizontal Parallax:



True Alt. = app. Alt + parallax

Parallax in alt. = horizontal parallax. Cos (app. Alt.)

The limiting value of horizontal parallax depends on the astronomical distance of the body from the earth and is appreciable only in the case of those navigational bodies within the solar system, the moon, sun and planets, being greatest in the case of the moon with an average value of about 60' given every hour in the Nautical Almanac.

STARS AND PLANETS			
App. Alt.	Corr^n	App. Alt.	Additional Corr^n
° ′	′		
9 56		1990	
	−5·3	VENUS	
10 08		Jan. 1–Feb. 8	
	−5·2	°	′
10 20		0	
	−5·1		+ 0·5
10 33		26	
	−5·0		+ 0·4
10 46		46	
	−4·9		+ 0·3
11 00		60	
	−4·8		+ 0·2
11 14		73	
	−4·7		+ 0·1
11 29		84	
	−4·6	Feb. 9–Feb. 23	
11 45		°	′
	−4·5	0	
12 01			+ 0·4
	−4·4	29	
12 18			+ 0·3
	−4·3	51	
12 35			+ 0·2
	−4·2	68	
12 54			+ 0·1
	−4·1	83	
13 13			
	−4·0		
13 33		Feb. 24–Mar. 18	
	−3·9		
13 54			

	MOON							Lat.
	G.H.A.		v	Dec.		d	H.P.	°
	°	′	′	°	′	′	′	N 72
.8	213	42.0	5.5	N25	36.3	2.6	58.2	N 70
.3	228	06.5	5.4	25	38.9	2.5	58.3	68
.7	242	30.9	5.3	25	41.4	2.3	58.3	66
.2	256	55.2	5.3	25	43.7	2.2	58.3	64
.6	271	19.5	5.2	25	45.9	2.0	58.4	62
.1	285	43.7	5.1	25	47.9	1.8	58.4	60
.5	300	07.8	5.1	N25	49.7	1.6	58.4	N 58
.0	314	31.9	5.0	25	51.3	1.5	58.5	56
.4	328	55.9	4.9	25	52.8	1.3	58.5	54
.8	343	19.8	4.9	25	54.1	1.2	58.6	52
.3	357	43.7	4.8	25	55.3	1.0	58.6	50
.7	12	07.5	4.8	25	56.3	0.8	58.6	45
.2	26	31.3	4.7	N25	57.1	0.6	58.7	N 40

Solved Example (1)

When solving an astronomical sight of the star ***Vega***; the following data were recorded:

- Sext. alt. 42º 12`.8
- I.E. 2`.2 off the arc
- Ht. of eye 13.4 m

Calculate True Altitude .

Answer :

Sext. alt.	42° 12`.8
I.E.	2`.2 (+)
Obs. alt.	42° 15`.0
Dip	6`.4 (-)
App. alt.	42° 08`.6
Corr.	1`.1 (-)
True alt.	42° 07`.5

Solved Example (2)

When solving an astronomical sight of the ***Sun's Lower Limb***, the following data were recorded:

- Sext. alt. 44º 22`.3
- I.E. 1`.7 on the arc
- Ht. of eye 11`.2 m
- G.M.T. 19h 15m 33s Jun. 15th ; 1984

Calculate True Altitude .

Answer :

Sext. alt.	44° 22`.3
I.E.	1`.7 (-)
Obs. alt.	44° 20`.6
Dip	5`.9 (-)
App. alt.	44° 14`.7
Corr.	15`.0 (+)
True alt.	44° 29`.7

Solved Example (3)

When solving an astronomical sight of the planet ***Venus***, the following data were recorded:

- Sext. alt. 24º 22`.3
- I.E. 1`.7 off the arc
- Ht. of eye 15`.2 m
- G.M.T. 10h 10m 03s Feb. 20th ; 1990

Calculate True Altitude .

Answer :

Sext. alt.	24º 22`.3
I.E.	1`.7 (+)
Obs. alt.	24° 24`.0
Dip	6`.9 (-)
App. alt.	24° 17`.1
Corr.	02`.1 (-)
Add. Corr.	00`.4 (+)
True alt.	24° 15`.4

STARS AND PLANETS

App. Alt.	Corr^n
9° 56′	
	−5′.3
10 08	
	−5.2
10 20	
	−5.1
10 33	
	−5.0
10 46	
	−4.9
11 00	
	−4.8
11 14	
	−4.7
11 29	
	−4.6
11 45	
	−4.5
12 01	
	−4.4
12 18	
	−4.3
12 35	
	−4.2
12 54	
	−4.1
13 13	
	−4.0
13 33	
	−3.9
13 54	

App. Alt.	Additional Corr^n
1990	
VENUS	
Jan. 1–Feb. 8	
0°	
	+ 0′.5
26	
	+ 0.4
46	
	+ 0.3
60	
	+ 0.2
73	
	+ 0.1
84	
Feb. 9–Feb. 23	
0°	
	+ 0′.4
29	
	+ 0.3
51	
	+ 0.2
68	
	+ 0.1
83	
Feb. 24–Mar. 18	

Solved Example (4)

When solving an astronomical sight of the ***Moon`s upper Limb****,* the following data were recorded:

- Sext. alt. 32º 35`.7
- I.E. 1`.5 off the arc
- Ht. of eye 15`.1 m
- G.M.T. 21h 10m 44s Dec. 20th ; 1984

Calculate True Altitude .

Answer :

Extracted HP from daily page (59`.1)

Sext. alt.	32º 35`.7
I.E.	1`.5 (+)
Obs. alt.	32° 37`.2
Dip	6`.8 (-)
App. alt.	32° 30`.4
Corr.	57`.8 (+)
Add. Corr.	4`.4 (+)
ɔ -30`	30`.0 (-)
True alt.	33° 02`.6

Solving the Spherical Triangle PZX

Introduction:

The spherical triangle PZX composed of three vertices :

- P (the elevated pole)
- Z (the zenith point)
- X (the celestial body concerned)

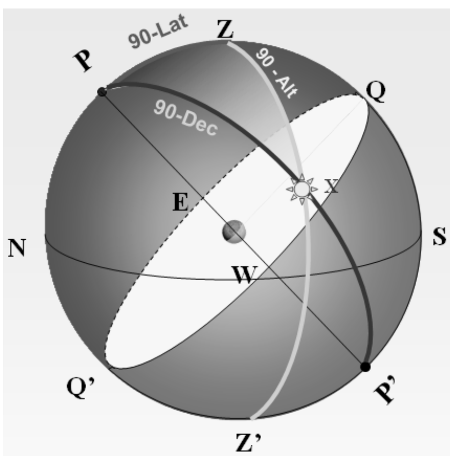
Where its angles are :

- Angle at the pole P is the Local hour angle (less than 180°).
- Angle at the zenith Z is the Azimuth (in semi-circular reckoning) .
- Angle at the celestial body X is called the parallactic angle .(hardly used in navigation)

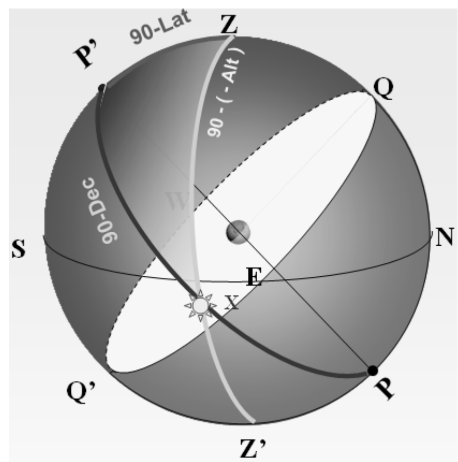
And its three sides are :

- PZ (co-latitude)
- PX (co-declination or polar distance)
- ZX (co-altitude or zenith distance)

Its importance arrives from the fact that ; it relates the horizon coordinates of the body to its equatorial coordinates and , what is particularly important , to the geographic coordinates of the observer (the longitude of the observer is contained through the local hour angle LHA).



The figure represents the celestial sphere for North latitude observer. North declination body is shown.



The figure represents the celestial sphere for South latitude observer. North declination body is shown.

The Spherical Triangle PZX and its solution:

A. Obtaining (Calculated Zenith Distance) side ZX

When solving the astronomical sights by Intercept method (Marcq St. Hilair method); we need to solve the problem of " given two sides and the included angle to obtain the third side " ; where in our case three variables are known in the spherical triangle PZX ;

1) Side PZ = 90º - D.R. Lat.
2) Side PX = 90º ± Dec.
3) Angle P = L.H.A.

It is required to obtain the 3rd side ZX which represents the Calculated Zenith Distance C.Z.D.
There are many ways to solve this problem; by applying the rules of the spherical trigonometry or by using Nautical Mathematical Tables .In this text we shall explain two methods to solve the problem by spherical trigonometry.

- Method (1): Using Haversine function.
- Method (2): Using Cosine formula.

Method (1) Haversine Function

The Haversine function has the advantage of being positive in all quadrants; and given by any of the following definitions :

$\text{hav}\ \theta = 0.5\ (1 - \cos\theta)$

OR

$\text{hav}\ \theta = \sin^2 (\theta / 2)$

To solve the problem "Given two sides and the included angle, to find the third side ", in the spherical triangle ABC; Given A, AB and AC, find BC the formula will be stated as follows:

hav [BC] = hav (A) sins (AB) sin (AC) + hav (AB ~ AC)

Applying the above formula to the spherical triangle PZX , where the following three variables are known :

- Side PZ = 90º - D.R. Lat.
- Side PX = 90º ± Dec.
- Angle P = L.H.A.

And it is required to obtain the 3rd side *ZX* which represents the Calculated Zenith Distance C.Z.D., the following relation is obtained :

hav ZX = hav P sin PZ sin PX + hav (PZ ~ PX).

By substitution; the final formula to be applied is stated as:

hav CZD = hav LHA. cos Lat. cos Dec. + hav (Lat. ~ Dec.)

Which can be solved in the suggested pattern:

LHA			hav.	
Lat.		x	Cos	
Dec.		x	Cos	
			hav.	
Lat. ~ Dec.		+	hav.	
CZD			hav.	

Solved Example (1)**:**

When solving an astronomical sight using Intercept method ;
the following results were obtained :

LHA	319º	40.2`
DR Lat	31º	15.2` N
Dec.	38º	45.6` N

Using personal calculator ; calculate CZD , applying Haversine function.
Solution:

LHA	319º 53`.8	hav.	0.11756
Lat.	33º 55`.0 S x	Cos	0.82985
Dec.	13º 15`.8 N x	Cos	0.97333
		hav.	0.09496
Lat.~ Dec.	47º 10`.8+	hav.	0.16015
CZD	**60º 40`.4**	hav.	0.25511

Solved Example (2)**:**

When solving an astronomical sight using Intercept method ;
the following results were obtained :

LHA	319º	53`.8
DR Lat	33º	55`.0 S
Dec.	13º	15`.8 N

Using personal calculator ; calculate CZD , applying Haversine function.
Solution:

LHA	319º 40.2`	hav.	0.11884
Lat.	31º 15.2` Nx	Cos	0.85488
Dec.	38º 45.6` Nx	Cos	0.77978
		hav.	0.07922
Lat.~ Dec.	7º 30`.4+	hav.	0.00429
CZD	**33º 35`.6**	hav.	0.08351

Method (2) Cosine Formula

The law of cosines for sides is a fundamental formula for solving a spherical triangle. As applied to spherical triangle ABC; the law is stated as:

- Cos a = Sin b . Sin c. Cos A + Cos b . Cos c
- Cos b = Sin a . Sin c .Cos B + Cos a . Cos c
- Cos c = Sin a . Sin b .Cos C + Cos a . Cos b

Applying the above formula to the spherical triangle PZX,
where the following three variables are known :

- Side PZ = 90º - D.R. Lat.
- Side PX = 90º ± Dec.
- Angle P = L.H.A.

And it is required to obtain the 3rd side ZX which represents the Calculated Zenith Distance C.Z.D. the following relation is obtained

$$\cos ZX = \sin PZ \ \sin PX \ \cos P + \cos PZ \ \cos PX$$

By substitution ; the final formula to be applied is stated as:

$$\cos CZD = \cos Lat. \ \cos Dec \ \cos LHA + \sin Lat. \sin Dec$$

When investigating the signs, bear in mind the following :

The latitude is always considered positive. The latitude is always numerically less than 90°; for this reason, all its trigonometric functions have the plus sign.

The declination may be of the same name as the latitude; then it should be considered positive; or it has a contrary name to the latitude; then it is negative; the declination is always less than 90°.

Regarding the previous investigations of signs; the final applicable formula will be in the following form :

$$\cos [CZD] = \cos (Lat.) \cos (Dec) \ \cos (LHA) \pm \sin (Lat.) \ \sin (Dec)$$

Positive sign is used in case of the latitude and declination are of same name.

Negative sign is used in case of the latitude and declination are of contrary name.

The formula can be solved using the following suggested pattern :

LHA		Cos			
Lat.		Cos		Sin.	
Dec.		Cos		Sin	
				±	
CZD		←			

Solved Example 1:

When solving an astronomical sight using Intercept method ;
the following results were obtained :

LHA 319° 40.2\`
DR Lat 31° 15.2\` N
Dec. 38° 45.6\` N

Using personal calculator ; calculate CZD; applying Cosine Formula.

Solution:

LHA	319° 40.2\`	Cos	0.76233		
Lat.	31° 15.2\` N x	Cos	0.85488	Sin.	0.51882
Dec.	38° 45.6\` N x	Cos	0.77978	Sin	0.62606
		+	0.50818	+	0.32481
CZD	**33° 35\`.6**	←	0.83299		

Solved Example 2:

When solving an astronomical sight using Intercept method ;
the following results were obtained :

LHA 159º 40.0`
DR Lat 61º 15.0` N
Dec. 48º 55.0` N

Using personal calculator ; calculate CZD , applying Cosine Formula.
Solution:

LHA	159º 40.0`	Cos	0.93769		
Lat.	61º 15.0` Nx	Cos	0.48099	Sin.	0.87673
Dec.	48º 55.0` Nx	Cos	0.65716	Sin	0.75375
		-	0.29639	+	o.66084
CZD	**68º 37`.6**	←	0.36445		

B. Obtaining Azimuth Angle Z.

Applying the well-known formula which connects four adjacent parts of a spherical triangle; which states :

*Cos (Inner side) * Cos (Inner angle) = Sin (Inner side) * Cot (Other side) - Sin (Inner angle) * Cot (Other angle)*

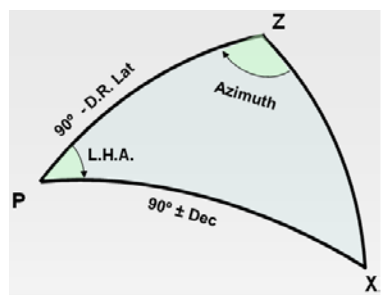
It can be shown, for instance, that in the spherical triangle ABC:

$\cos PZ * \cos P = \sin PZ * \cot PX - \sin P * \cot Z$

Dividing by (sin P * sin PZ)

$$\frac{\cos PZ * \cos P}{\sin P * \sin PZ} = \frac{\sin PZ * \cot PX}{\sin P * \sin PZ} - \frac{\sin P * \cot Z}{\sin P * \sin PZ}$$

$\cot PZ * \cot P = \cot PX * \operatorname{cosec} P - \operatorname{cosec} PZ * \cot Z$



tan Lat. * cot LHA = tan Dec * cosec LHA - sec Lat. * cot Z

i.e.

*sec. Lat. * cot Z = tan Lat. * cot LHA - tan Dec * cosec LHA*

Naming tan Lat. * cot. LHA as A

and tan Dec * cosec LHA as B

Hence cot. Z = (A + or ~ B) * $_{cos}$. Lat.

(A + or ~ B), referred to for convenience as C

Thus we have: *cot. Z = C * cos. Lat.*

Neglecting the sins of the parameters; A, B and C **we** name them as follows**:**

A: *named opposite to Latitude except when L.H.A. is contained between 90° & 270°.*

B: *named always as Declination.*

C: *takes the name of the resultant of A & B.*

The Azimuth Z is denoted N or S as C **and** E or W according to the value of the L.H.A.

Note:

(W) if L.H.A. < 180° and (E) if L.H.A. > 180°.

Solved Example (1)

Given the following parameters for a certain heavenly body and a certain observer;

L.H.A. 297° 08`.8

Latitude 40° 12`.0 N

Declination 12° 00`.8 N

Calculate the True Bearing of that body.

Solution:

L.H.A.	297 08.8	A	0.433 S
Lat.	40 12.0 N	B	0.239 N
Dec.	12 00.8 N	C	0.194 S
		Az.	S 81.6 E
		T. Bg.	098.4

A: is named opposite to lat.

B: has the same name as Dec.

C: has the name of A which is numerically greater than B.

The Azimuth is named S because C is S; and E because LHA > 180°.

Solved Example (2)

Given the following parameters for a certain heavenly body and a certain observer ;

L.H.A. 244° 48`.1

Latitude 41° 19`.3 S

Declination 5° 10`.7 S

Calculate the True Bearing of that body.

Solution:

L.H.A.	244 48.1	A	0.414 S
Lat.	41 19.3 S	B	0.100 S
Dec.	5 10.7 S	C	0.514 S
		Az.	S 68.9 E
		T. Bg.	111.1

A: is named same name as lat. because L.H.A. is between 90° and 270°.

B: has the same name as Dec.

C = A + B has the name as A & B

The Azimuth is named S because C is S; and E because LHA > 180°.

Twilight Phenomena

Introduction:

There are several phenomena associated with the rising and setting of the sun and other celestial bodies of significance and consequent interest to the navigator. The most important of these are twilight, sunrise, sunset, moonrise and moonset.

Twilight is the period before sunrise when darkness is giving way to daylight, and after sunset, when the opposite progression takes place.

Morning twilight ends at sunrise, defined as the first appearance of the sun's upper limb above the visible horizon, and evening twilight begins at sunset, or the disappearance of the sun's upper limb below the horizon. Moonrise and moonset are defined similarly to sunrise and sunset, by the contact of the upper limb of the moon with the visible horizon.

Twilight is of special interest to the navigator, as this is the only time when the visible horizon is still light enough to be clearly defined, while the navigational stars and planets are bright enough to be observed with a marine sextant. Sunrise and sunset are only slightly less important, it the time at which the navigator calculate the Amplitude to obtain compass error.

Definitions

Twilight is defined according to the solar elevation angle; which is the position of the geometric center of the sun relative to the horizon. There are three established and widely accepted *subcategories* of twilight: civil twilight (brightest), nautical twilight, and astronomical twilight (darkest).

A. CIVIL TWILIGHT

Morning civil twilight begins when the geometric center of the sun is 6° below the visible horizon (**civil dawn**) and ends at visible sunrise. Evening civil twilight begins at visible sunset and ends when the geometric center of the sun reaches 6° below the visible horizon (**civil dusk**). The brightest planets can appear during this time. Venus, the brightest planet as observed from the Earth is known as the "morning star" before sunrise or "evening star" after sunset.

At the beginning of morning civil twilight, or end of evening civil twilight, the visible horizon is clearly defined and the brightest stars are visible under clear atmospheric conditions.

B. NAUTICAL TWILIGHT

Nautical twilight is the time when the center of the sun is between 6° and 12° below the horizon. In general, nautical twilight ends when navigation via the horizon at sea is no longer possible. During nautical twilight, sailors can take reliable star sightings of well-known stars, using a visible horizon for reference.

C. ASTRONOMICAL TWILIGHT

Astronomical twilight is the time when the center of the sun is between 12° and 18° below the visible horizon.

Theoretically, the dimmest stars ever visible to the naked eye (those of the sixth magnitude), will become visible in the evening once the sun falls more than 18° below the visible horizon (*i.e.*, at astronomical dusk), and become invisible when the sun moves to within 18° of the visible horizon in the morning (at astronomical dawn).

Twilight between day and night

The most familiar occurrences of twilight are between dawn and sunrise and between sunset and dusk each day. These occur for observers at latitudes within 48°.5 of the Equator on all dates of the year, and also for most observers at higher latitudes on many dates.

Twilight lasting from one day to the next

At latitudes greater than about 48.5 degrees North or South, on dates near the summer solstice, twilight can last from sunset to sunrise, since the Sun does not go more than 18 degrees below the visible horizon, so complete darkness does not occur even at midnight.

Twilight between one night and the next, or for 24 hours:

In Arctic and Antarctic latitudes in wintertime, the polar night only rarely produces complete darkness for 24 hours each day. This can occur only at locations within 5.5 degrees of latitude of the Pole, and there only on dates very close to the winter solstice. At all other latitudes and dates, the polar night includes a daily period of twilight, when the Sun is not far below the visible horizon.

Length

The number of daylight hours depends on the latitude and time of year. Each pole has continuous daylight near its summer solstice.

The length of twilight after sunset and before sunrise is heavily influenced by the *latitude* of the observer. In the Arctic and Antarctic regions, twilight (if there is any) can last for several hours. There is no astronomical twilight at the poles near the winter solstice (for about 74 days at the North Pole and about 80 days at the South Pole). At the poles, civil twilight can be as long as 2–3 weeks, while at the equator, conditions can go from day to night in as little as 20–25 minutes. This is true because at low latitudes the sun's apparent movement is perpendicular to the observer's horizon. As one gets closer to the Arctic and Antarctic circles, the sun's disk moves toward the observer's horizon at a lower angle.

Solved Example (1)

Calculate Z.T. of each of sunrise and sunset phenomena hence the interval of **direct Day Light** at **Shortest Day** for an observer in DR position (62° 00`.0 N; 159° 15`.0 W)?
Answer:

- **Shortest** Day for north latitude observer occurs at 22nd December..
- Calculations:

	Sun Rise	Sun Set
L.M.T. Lat. Corr^n.	9 24 + 28 00	14 33 -29 00
L.M.T. ± Long. (+)	9 24 10 37	14 33 10 37
G.M.T. Z.N. (-)	20 01 11	25 10 11
Z.T.	09 01	14 10

- Z.T. of sunrise 09h 01m
- Z.T. of sunset 14h 10m
- Interval of Day Light = [14h 10m - 9h 01m] = 5h 09m

Solved Example (2)

Calculate Z.T. of each of sunrise and sunset phenomena hence the interval of **direct Day Light** at **Longest Day** for an observer in DR position (60° 00`.0 S; 159° 15`.0 W)?

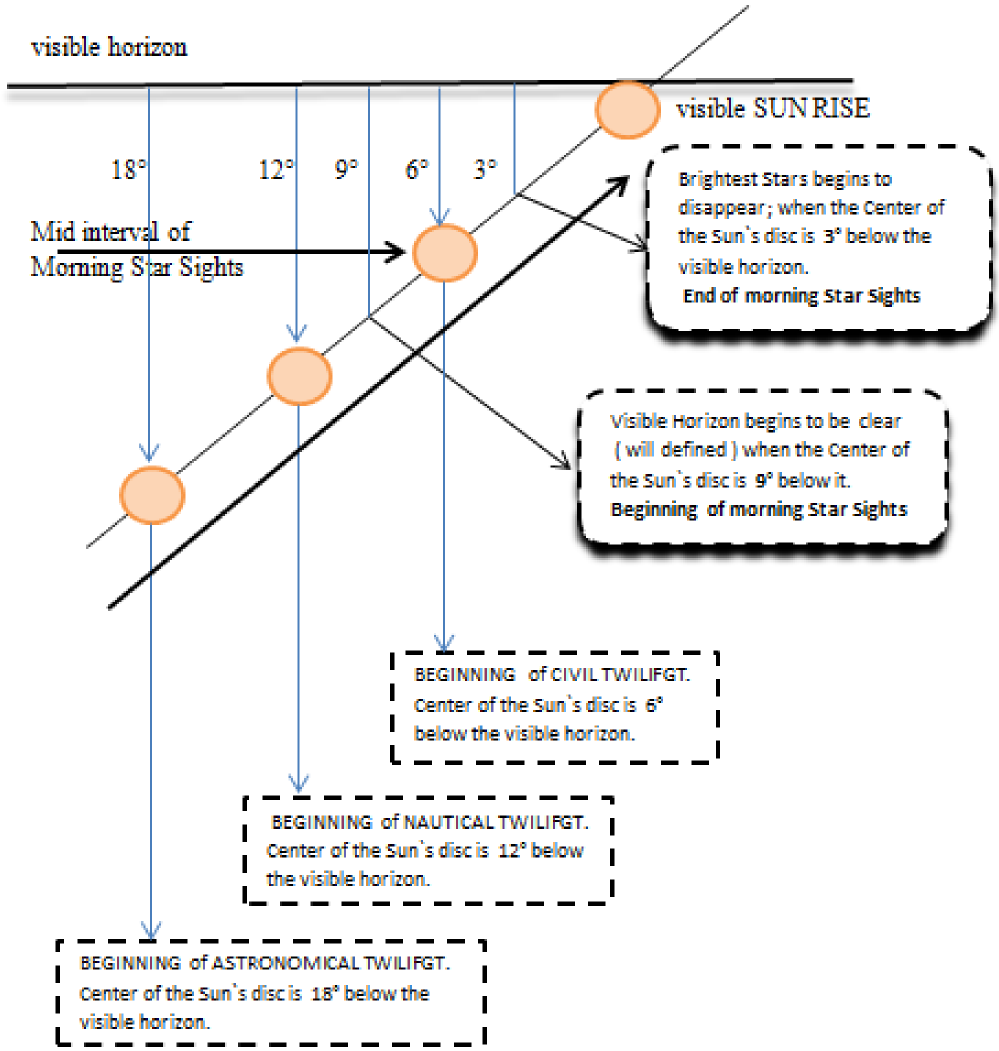
Answer:

- **Longest** Day for south latitude observer occurs at 22nd December
- Calculations:

	Sun Rise	Sun Set
L.M.T. Lat. Corr^n.	2 32 ?? 00	21 25 ?? 00
L.M.T. ± Long. (+)	2 32 10 37	21 25 10 37
G.M.T. Z.N. (-)	13 09 11	32 02 11
Z.T.	02 09	21 02

- Z.T. of sunrise 02h 09m
- Z.T. of sunset 21h 02m
- Interval of Day Light = [21h 02m - 2h 09m] = 18h 53m

==========


visible horizon
visible SUN RISE
18°
12°
9°
6°
3°
Mid interval of
Morning Star Sights
Brightest Stars begins to disappear; when the Center of the Sun`s disc is 3° below the visible horizon.
End of morning Star Sights
Visible Horizon begins to be clear (will defined) when the Center of the Sun`s disc is 9° below it.
Beginning of morning Star Sights
BEGINNING of CIVIL TWILIFGT.
Center of the Sun`s disc is 6° below the visible horizon.
BEGINNING of NAUTICAL TWILIFGT.
Center of the Sun`s disc is 12° below the visible horizon.
BEGINNING of ASTRONOMICAL TWILIFGT.
Center of the Sun`s disc is 18° below the visible horizon.

Solved Example (3)

On January 8th, 1990; for an observer in DR position (33° 30`.0 N; 19° 45.0 W);
Calculate:

1. Z.T. of the beginning of morning star sight.
2. Z.T. of the end of morning star sight.
3. Interval of morning star sight.

Answer:

	Naut. Tw.	Civil Tw.	Sun Rise
L.M.T. Lat. Corr^n.	06 01 (+8) 06	06 31 (+10) 07	06 57 (+12) 08
L.M.T. ± Long. (+)	06 07 Jan 8th 01 19	06 38 Jan 8th 01 19	07 05 Jan 8th 01 19
G.M.T. Z.N. R (-)	07 26 Jan 8th 1	07 57 Jan 8th 1	08 24 Jan 8th 1
Z.T.	06 26 Jan 8th	06 57 Jan 8th	07 24 Jan 8th

Morning star sights begins at ZT	06h 41m 30s
Morning star sights end at ZT	07h 10m 30s
Interval of morning star sights	29 m

Solved Example (4)

On March 15th, 1990; for an observer in DR position (43° 30`.0 S; 149° 45.0 E);
Calculate:

1. Z.T. of the beginning of evening star sight.
2. Z.T. of the end of evening star sight.
3. Interval of evening star sight.

Answer:

	Sunset	Civil Tw.	Naut. Tw.
L.M.T. Lat. Corr^n.	18 20 (+2) 01	18 47 (+4) 03	19 19 (+7) 05
L.M.T. ± Long. (-)	18 21 Mar 15th 09 59	18 50 Mar 15th 09 59	19 24 Mar 15th 09 59
G.M.T. Z.N. (+)	08 22 Mar 15th 10	08 51 Mar 15th 10	09 25 Mar 15th 10
Z.T.	18 22 Mar 15th	18 51 Mar 15th	19 25 Mar 15th

Evening star sights begins at ZT 18h 36m 30s
Evening star sights ends at ZT 19h 08m 00s
Interval of Evening star sights 31m 30s

Solved Example (5)

Calculate Z.T. of Sun Rise given the following information:

- Z.T. 2300 May 10th 1990
- D.R. Position 40° 05`.0N;115° 50`.0 E
- True Course to steer 200°.0
- Speed 18.5 knots

Answer:

1st Approximation

	Sun Rise
L.M.T.	04 49 (-13)
Lat. Corrn.	00
L.M.T.	04 49 May 11th
± Long.1 (-)	7 43
G.M.T.1	21 06 May 10th
Z.N.1 (+)	8
Z.T.2	05 06 May 11th
Z.T.1 (-)	2300 May 10th
Interval	6h 06m
Dist. Run	112.9 M
T. Course	200°.0

Calculation of Run

d. Lat.	Dep.	m. Lat.	d. Long.
106.1S	38.6W	39°.2	47`.8W

Lat.1	40° 05`.0N	Long.1	115° 50`.0 E
d. Lat.	01° 46`.1S	d. Long.	0° 47`.8W
Lat.2	38° 18`.9N	Long.2	115° 02`.2E

2nd Approximation

	Sun Rise
L.M.T.	05 00 (-11)
Lat. Corrn.	07
L.M.T.	04 53 May 11th
± Long.2 (-)	7 40
G.M.T.2	21 13 May 10th
Z.N.2 (+)	8
Z.T.3	**05 13 May 11th**

Solved Example (6)

Calculate Z.T. of Sun Set given the following information:

• Z.T.	1300 May 10th 1990
• D.R. Position	41° 35`.0N;125° 40`.0 E
• True Course to steer	190°.0
• Speed	18.5 knots

Answer:

1st Approximation

	Sun Set
L.M.T.	19 04 (+13)
Lat. Corrn.	04
L.M.T.	19 08 May 10th
± Long.$_1$ (-)	8 23
G.M.T.$_1$	10 45 May 10th
Z.N.$_1$ (+)	8
Z.T.$_2$	18 45 May 10th
Z.T.$_1$ (-)	13 00 May 10th
Interval	5h 45m
Dist. Run	106.4 M
T. Course	190°.0

Calculation of Run

d. Lat.	Dep.	m. Lat.	d. Long.
104`.8 S	18`.5W	40°.7	24`.4W

Lat.$_1$	41° 35`.0N	Long.$_1$	125° 40`.0 E
d. Lat.	01° 44`.8S	d. Long.	0° 24`.4W
Lat.$_2$	39° 50`.2N	Long.$_2$	125° 15`.6E

2nd Approximation

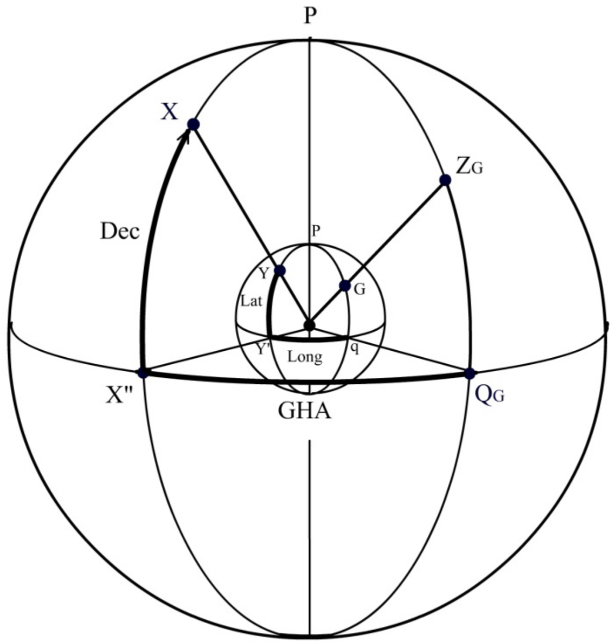
	Sun Set
L.M.T.	18 53 (+11)
Lat. Corrn.	11
L.M.T.	19 04 May 10th
± Long.$_2$ (-)	8 21
G.M.T.$_2$	10 43 May 10th
Z.N.$_2$ (+)	8
Z.T.$_3$	**18 43 May 10th**

Theory of the Astronomical Position Line

Geographical Position

Definition:

Geographical Position of a Celestial Body is the point of intersection of the line joining the centers of the celestial body and Earth; with Earth`s surface.



The figure represents; the Earth centered with the celestial sphere; where:

X the celestial body & PXX" is the meridian of the body.
Y the geographical position & pYY" is the meridian of the GP
G Position of Greenwich
Z_G Zenith of Greenwich & **PZ_GQ_G** is the upper meridian of Greenwich.

The arc X"X on the celestial sphere is the declination of the body (Dec_*)
The arc Y"Y on the Earth is the Latitude of the GP. ($Lat._{GP}$)
Since X"X & Y"Y subtends the same angle;
We get: $Lat._{GP} = Dec_*$
The arc Q_GX" on the celestial sphere is the GHA of the body (GHA_*)
The arc q Y" on the Earth is the Longitude of the GP. ($Long._{GP}$)
Since Q_GX"& q Y" subtends the same angle;
We get: $Long._{GP} = GHA_*$

Note:

$Long._{GP}$ is denoted West if < 180°; and if it was > 180° subtract from 360° then denote it East.

SOLVED EXAMPLE (1)

At the morning civil twilight on October 12th; 1990.
Ship was in D.R. position (36º 16`.0 S; 175º 18`.0 E).

- Ch.Time 05h 08m 03s
- Ch. Error 4m 44s slow

Calculate the Geographical Position of the star *Achernar*.

Answer:

≈ L.M.T.	0458 Oct 12th
± Long. w/ E	1141 (-)
G.D.	1717 Oct 11th

Ch. Time	5h 08m 03s
Ch. Error	04m 44s (+)
G.M.T.	17h 12m 47s

G.H.A.♈	275 01.4
Incr. ♈	3 12.3
SHA	335 38.5
G.H.A.	253 52.2 W

Dec.* 57 16.8 S

According to definition, H.A. is denoted west

Applying: Lat.$_{GP}$ = Dec*
Long.$_{GP}$ = GHA*

When Long. > 180°; subtract from 360° and reverse notation.

The G.P. Is (57° 16`.8 S; 106° 07`.8 E)

SOLVED EXAMPLE (2)

At Z.T. 1455 on April 18th; 1990.
Ship was in D.R. position (51º 07`.0 N; 174º 50`.0 W).

- Ch.Time 3h 02m 58s
- Ch. Error 5m 18s fast

Calculate the Geographical Position of the *Sun*.:

Answer:

Z.T.	1455 Apr 18th
Z.N.	12 (+)
G.D.	0255 Apr 19th

Ch. Time	03h 02m 58s
Ch. Error (-)	05m 18s
G.M.T.	02h 57m 40s Apr 19th

.

G.H.A.	210 11.5	Dec.*	11 02.1 N
Incr.	14 25.0	d^c	0.9 (+)
G.H.A.	224 36.5 W	C.Dec.*	11 03.0 N

Applying: Lat.$_{GP}$ = Dec*
Long.$_{GP}$ = GHA*

When Long. > 180°; subtract from 360° and reverse notation.

The G.P. is (11° 03`.0 N ; 135° 23`.5 E)

SOLVED EXAMPLE (3)

Z.T. 1750 of January 7th; 1990.
Ship was in D.R. position (29º 10`.2 N; 136º 20`.4 W)

- Ch. Time 02h 40m 00s
- Ch. Error 5m 22s slow

Calculate the Geographical Position of the star *Polaris*.

Answer:

Z.T.	1750 Jan. 7th
Z.N. (+)	9
G.D.	0250 Jan. 8th

Ch. Time	02h 40m 00s
Ch. Error (+)	05m 22s
G.M.T.	02h 45m 22s Jan. 8th

The star Polaris (α Ursæ Minoris) is not tabulated in daily pages of the *Nautical Almanac* Tables.
Its SHA & Dec. are obtained from pages of Constellations of stars.

Sea next page

G.H.A. γ	137 22.1	
Incr.	11 22.4	
G.H.A. γ	148 44.5	
S.H.A. *	324 38.9	Dec → 89 13.6 N
G.H.A.*	113 23.4 W	

Applying: $Lat._{GP} = Dec_{*}$
$Long._{GP} = GHA_{*}$

The G.P. Is (89° 13`.6 N; 113° 23`.4 W)

272

STARS, 1990 JANUARY—JUNE

Mag.	Name and Number		S.H.A.							Declination						
				JAN.	FEB.	MAR.	APR.	MAY	JUNE		JAN.	FEB.	MAR.	APR.	MAY	JUNE
			°	′	′	′	′	′	′	°	′	′	′	′	′	′
1·6	α Geminorum		246	29·9	29·8	29·9	30·1	30·2	30·2	N. 31	54·7	54·7	54·7	54·8	54·7	54·7
3·3	σ Puppis		247	45·7	45·8	45·9	46·1	46·3	46·4	S. 43	16·8	17·0	17·1	17·1	17·1	17·0
3·1	β Canis Minoris		248	20·3	20·3	20·4	20·5	20·6	20·6	N. 8	18·6	18·6	18·6	18·6	18·6	18·6
2·4	η Canis Majoris		249	04·0	04·0	04·1	04·3	04·4	04·5	S. 29	17·0	17·1	17·2	17·2	17·2	17·1
2·7	π Puppis		250	47·6	47·6	47·8	48·0	48·1	48·2	S. 37	04·7	04·9	05·0	05·0	04·9	04·8
2·0	δ Canis Majoris		252	59·7	59·7	59·8	60·0	60·1	60·2	S. 26	22·6	22·7	22·8	22·8	22·8	22·7
3·1	ο Canis Majoris		254	20·4	20·4	20·5	20·7	20·8	20·8	S. 23	49·1	49·2	49·3	49·3	49·2	49·1
1·6	ε Canis Majoris	19	255	26·0	26·0	26·1	26·3	26·4	26·5	S. 28	57·5	57·6	57·7	57·7	57·6	57·5
2·8	τ Puppis		257	34·1	34·2	34·4	34·6	34·8	34·9	S. 50	36·2	36·3	36·4	36·4	36·3	36·2
1·8	β Tauri	14	278	34·5	34·6	34·7	34·8	34·9	34·8	N. 28	36·1	36·2	36·1	36·1	36·1	36·1
1·7	γ Orionis	13	278	50·6	50·6	50·7	50·9	50·9	50·9	N. 6	20·6	20·5	20·5	20·5	20·5	20·6
0·2	α Aurigæ	12	281	00·1	00·2	00·3	00·5	00·5	00·5	N. 45	59·5	59·6	59·6	59·6	59·5	59·4
0·3	β Orionis	11	281	28·7	28·7	28·8	29·0	29·0	29·0	S. 8	12·7	12·8	12·8	12·8	12·7	12·6
2·9	β Eridani		283	09·1	09·2	09·3	09·5	09·5	09·5	S. 5	05·9	05·9	05·9	05·9	05·9	05·8
2·9	ι Aurigæ		285	54·3	54·4	54·5	54·7	54·7	54·6	N. 33	09·3	09·3	09·3	09·2	09·2	09·2
1·1	α Tauri	10	291	09·3	09·4	09·5	09·6	09·6	09·5	N. 16	29·5	29·5	29·5	29·5	29·5	29·5
3·2	γ Eridani		300	36·1	36·2	36·4	36·5	36·5	36·4	S. 13	32·2	32·2	32·2	32·2	32·1	32·0
3·0	ε Persei		300	41·8	41·9	42·1	42·2	42·2	42·0	N. 39	59·2	59·2	59·2	59·1	59·1	59·0
2·9	ζ Persei		301	37·0	37·1	37·2	37·3	37·3	37·2	N. 31	51·5	51·5	51·5	51·4	51·4	51·4
3·0	η Tauri		303	16·2	16·3	16·5	16·5	16·5	16·4	N. 24	04·7	04·7	04·7	04·6	04·6	04·6
1·9	α Persei	9	309	05·4	05·6	05·8	05·9	05·9	05·7	N. 49	49·9	49·9	49·9	49·8	49·7	49·6
Var.§	β Persei		313	06·9	07·0	07·2	07·2	07·2	07·0	N. 40	55·4	55·4	55·3	55·2	55·2	55·1
2·8	α Ceti	8	314	33·3	33·4	33·5	33·6	33·5	33·4	N. 4	03·2	03·1	03·1	03·1	03·2	03·3
3·1	θ Eridani	7	315	31·4	31·5	31·7	31·8	31·8	31·7	S. 40	20·8	20·8	20·7	20·6	20·5	20·3
2·1	α Ursæ Minoris		324	38·9	49·8	58·5	62·9	59·9	51·8	N. 89	13·6	13·6	13·6	13·4	13·3	13·2
3·1	β Trianguli		[illegible]	[illegible]	45·7	45·8	45·8	45·7	45·5	N. 34	[illegible]	56·7	56·6	56·5	56·5	56·5
2·2	α Arietis	6	[illegible]	20·6	20·7	20·8	20·8	20·7	20·5	N. 23	25·1	[illegible]	25·1	25·0	25·0	25·1

Degrees of Dec. Minutes of Dec.

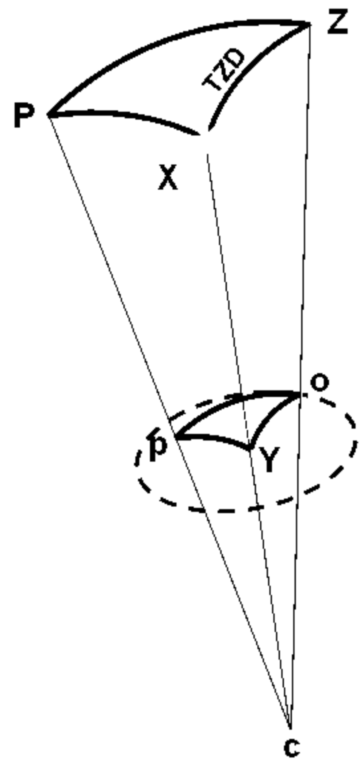
The star Polaris

Degrees of SHA Minutes of SHA

Position Circle

It is known that the Geographical Position (G.P.) of any celestial body can be obtained at any instant of universal time (G.M.T.) from the equations:

$$\text{Lat.}_{GP} = \text{Dec}_*$$
$$\text{Long.}_{GP} = \text{GHA}_*$$

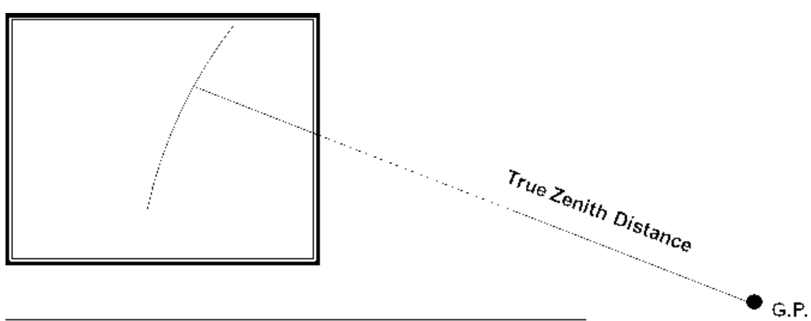


At the same time; the sextant altitude can be obtained hence the True Zenith Distance (T.Z.D.). Thus, at the moment of recording the sight (G.M.T.) we should have the following data on Earth`s surface:

- Coordinates of the point Y representing the G.P. of the body concerned.
- The arc OY which equals the True Zenith Distance T.Z.D. (i.e. the distance of true position of the observer O from the G.P.).

The Locus of the true position of the observer will be a circle centered at Y and of radius T.Z.D. This circle is known as the ***position circle***

Position Line



Practically, the radius of the position circle is thousands of Nautical Miles. This means that it is impossible to construct the circle & its center on the navigational chart.

The problem is summarized as follows:

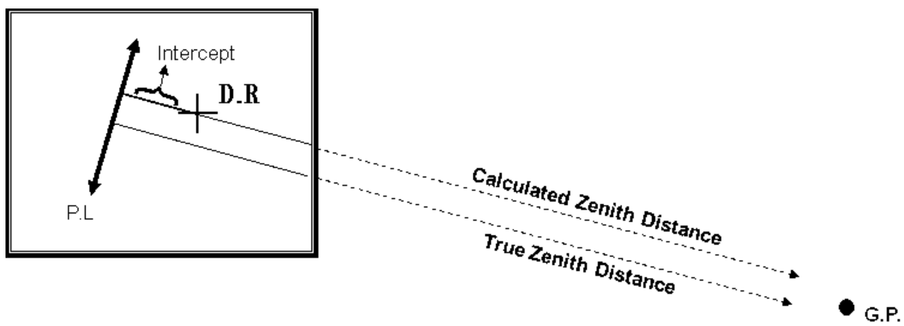
How to construct the portion of the position circle on the navigational chart; while its center is very far from the area of this chart?

In 1878, *Marcq St. Hilair*, a French naval officer, solved this problem in a creative way which is can be summed up as follows :

He assumed that, the ship is situated in the D.R. position O_1 at the moment of the observation; so its zenith point will be at Z_1. The spherical triangle PZ1X is formed. The known parts of this triangle are:

a) Side PZ1 = 90º - D.R. Lat.
b) Side PX = 90º - Dec.
c) Angle P = L.H.A. = G.H.A. ± D.R. Long

By solving this triangle, we obtain the side Z_1X which represents the distance of the body from the D.R. position O_1 on Earth. This side is named Calculated Zenith Distance (C.Z.D.).

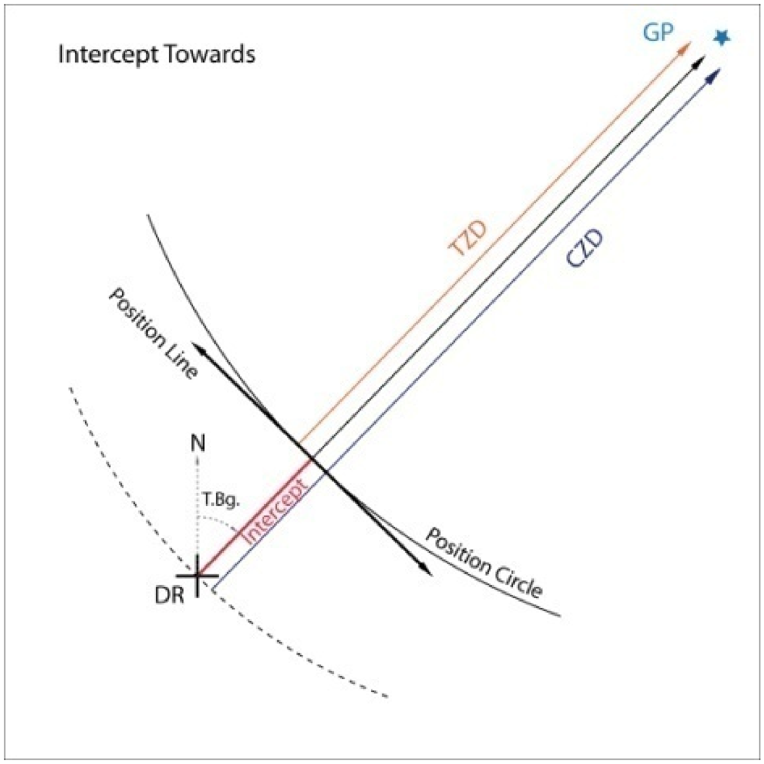


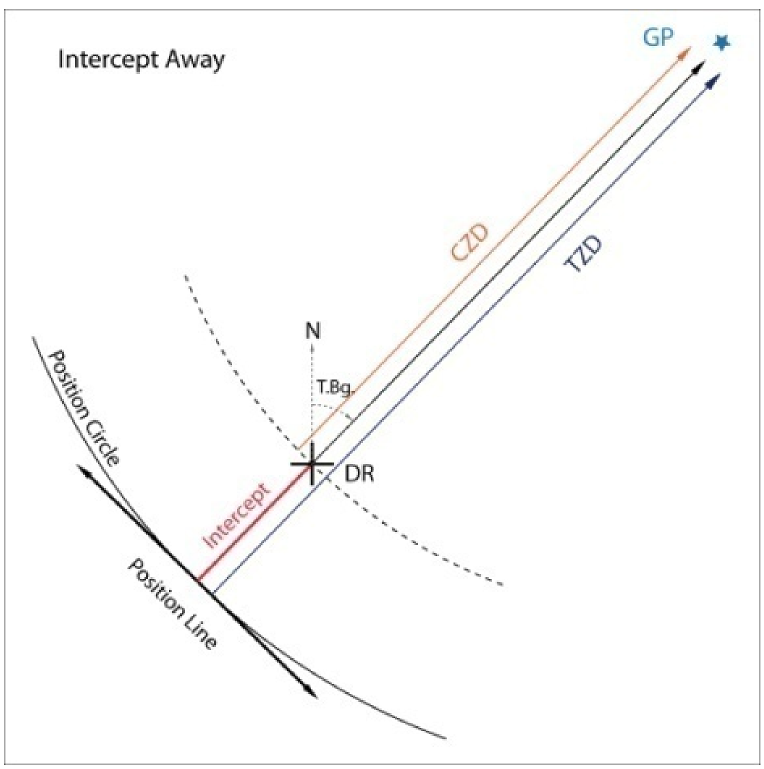
Now, on the navigational chart we have:

1) The D.R. position.
2) The distance between the D.R. position and the G.P; known as (C.Z.D.)
3) The distance between the actual position of the ship and the G.P. is known. (T.Z.D.) .
4) The numerical difference between C.Z.D. & T.Z.D. is a small value known as the *Intercept*
5) The portion of the position circle, nearer to the D.R., considered as a straight line (Since the radius of the circle is thousands of nautical miles.

The Position Line can be constructed on the navigational chart in steps as follows:

1) From the D.R. position; draw the true bearing of the body.
2) Starting from the D.R. position; measure the intercept in N.M.^{s} in the direction of the body if C.Z.D. > T.Z.D. (the intercept is denoted towards) and in the opposite direction if C.Z.D. < T.Z.D. (the intercept is denoted away) sees next figures.
3) From the end point of measuring the intercept construct a perpendicular to the true bearing. This perpendicular line is the Position Line.


Intercept Towards
GP
TZD
CZD
Position Line
N
T.Bg.
Intercept
DR
Position Circle


Intercept Away
GP
CZD
TZD
N
T.Bg.
DR
Position Circle
Intercept
Position Line

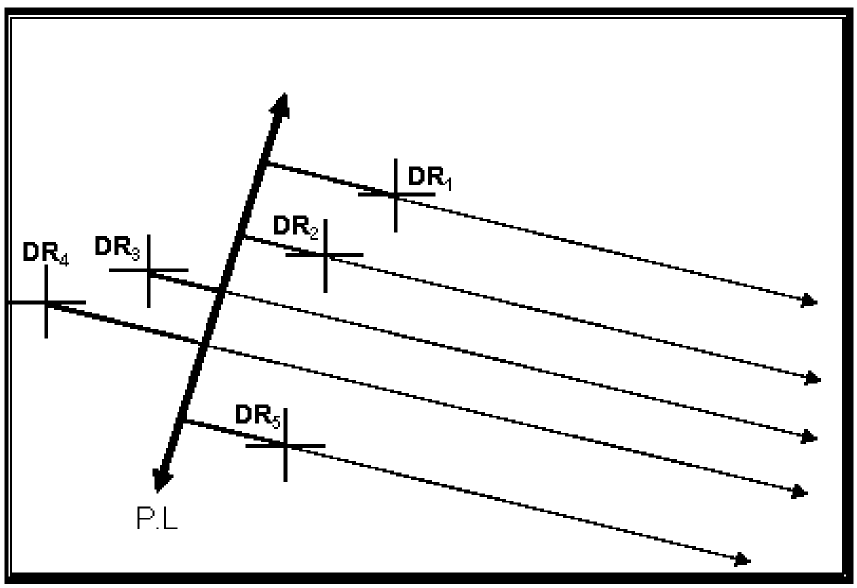
Important Comment

Whatever the error in the D.R. position used in the solution, we shall obtain the same P.L. on the chart. Only one condition must be applied:

The P.L. must be constructed from the D.R. position used in the solution.

This is proved easily by solving the same sight by many assumed D.R **(i)** positions. The result of solutions will be different values of Intercept **(i)** and the same value of true bearing (approximately). If we construct the Position Lines, they will be coinciding.

According to this fact, the concept of the chosen position was used to simplify the calculations of CZD when using sight reduction tables; but this is not the case when using the hand calculator.



Solved Example

Three navigators (A, B and C) solve the same star sight at the same GMT; but they used different positions as follows:

	DR position of solution	Results of solution	
		True Bg.	Intercept
Navigator (A)	44° 52`.6 N; 123° 20`.5 W	300°.0	3`.5 Away
Navigator (B)	44° 50`.0 N; 123° 22`.5 W		
Navigator (C)	44° 54`.1 N; 123° 18`.0 W		

Assuming that the true bearings are the same from all points in the neighborhood of the DR position (A); Use a plotting sheet (Or a paper) to extract intercepts must be obtained for navigators (B) and (C)?

Answer:

Step (1): To find d. Lat. & dep. for each of DR $_B$ and DR $_C$ with respect to DR $_A$

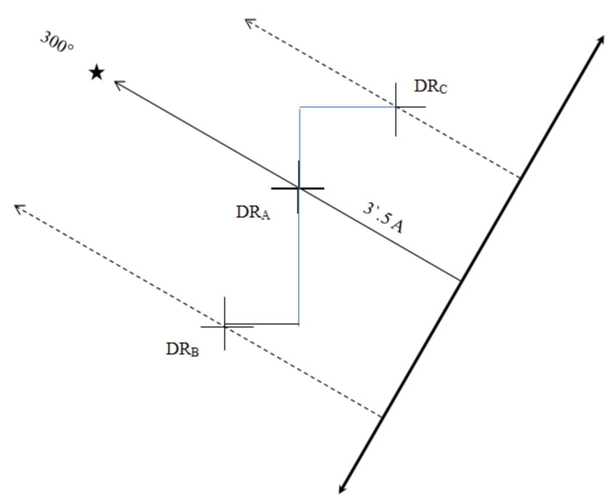
Lat. $_A$	44° 52`.6 N	Long. $_A$	123° 20`.5 W
Lat. $_B$	44° 50`.0 N	Long. $_B$	123° 22`.5 W
d. Lat.	2`.6 S	d. Long.	2`.0 W
		dep.	1`.4 W

Lat. $_A$	44° 52`.6 N	Long. $_A$	123° 20`.5 W
Lat. $_C$	44° 54`.1 N	Long. $_C$	123° 18`.0 W
d. Lat.	1`.5 N	d. Long.	2`.5 E
		dep.	1`.8 E

Step (2): Plotting and Extracting results;

Intercept for navigator B → 3`.4 A

Intercept for navigator C → 2`.6 A



Astronomical Position Line

Suggested Pattern of Solution (case of star)

In case of given ZT		In case of given Twilight	
Z.T.		≈ LMT	
Z.N. (±)		± Long. (W/E)	
G.D.		GD	
Ch. Time		Ch. Time	
Ch. Error		Ch. Error	
G.M.T.		G.M.T.	

GHA γ			
Incr. γ			
SHA		Dec.	---------------
GHA			
± Long.			
LHA			

Cos[CZD] = Cos[LHA]* Cos[Lat.]* Cos[Dec.] ± Sin[Lat.]* Sin[Dec.]

Cos[CZD] = Cos[------------]* Cos[----------]* Cos[----------] + Sin[-----------]* Sin[----------]

Cos[CZD] = ----------- $\longrightarrow$ CZD -------------

LHA	A	
Lat.	B	
Dec.	C	
	Az.	
	T. Bg.	

Sext. alt.	
IE ( )	
Obs. alt.	
Dip (-)	
App. alt.	
Corr.$^{\underline{n}}$ ( )	
True alt.	
90 (~)	
TZD	
CZD	
Inter.	

Astronomical Position Line
Suggested Pattern of Solution (case of sun)

Z.T. Z.N. (±)	
G.D.	

Ch. Time Ch. Error	
G.M.T.	

GHA Incr.		Dec d. Corr.$^{\underline{n}}$	
GHA ± Long.		C. Dec.	
LHA			

Cos [CZD] = Cos[LHA]* Cos[Lat.]* Cos[Dec.] ± Sin[Lat.]* Sin[Dec.]

Cos[CZD] = Cos[------------]* Cos[----------]* Cos[----------] + Sin[------------]* Sin[----------]

Cos [CZD] = ------------ $\longrightarrow$ CZD --------------

LHA Lat. Dec.	A B	
	C	
	Az.	
	T. Bg.	

Sext. alt. IE ( )	
Obs. alt. Dip (-)	
App. alt. Corr.$^{\underline{n}}$ ( )	
True alt. 90 (~)	
TZD CZD	
Inter.	

SOLVED EXAMPLE (1)
At Evening Civil Twilight on March 13th ; 1990.
Ship was in D.R. position (39º 59`.0 N; 160º 59`.0 W)

- I.E. 2`.2 on the arc
- Ht. of eye 13.3 m
- Ch. error 3m 41s slow

The star *Alpheratz* **was** observed as follows:

- Ch.Time 05h 10m 09s
- Sext.alt. 20º 20`.0

Find the elements of the position line by Intercept method.
Answer:

1st Step: To Adjust Time Of G.M.T.

L.M.T.	1830 Mar. 13th
± Long. w/ E	1044 (+)
G.D.	0514 Mar. 14th

Ch. Time	5h 10m 09s
Ch. Error	3m 41s (+)
G.M.T.	05h 13m 50s Mar. 14th

2nd Step: To Extract L.H.A. & Dec.

G.H.A.	246 33.5		
Incr.	3 28.1		
SHA	358 02.0	Dec.*	N 29 02.2
G.H.A.			
± long (E/W)	160 59.0 (-)		
L.H.A.	087 04.6		

3rd Step: To Calculate C.Z.D

$$\text{Cos [CZD]} = \text{Cos[LHA]} * \text{Cos[Lat.]} * \text{Cos[Dec.]} \pm \text{Sin[Lat.]} * \text{Sin[Dec.]}$$

$$\text{Cos[CZD]} = \text{Cos}[087\ \ 04.6] * \text{Cos}[39\ \ 59.0] * \text{Cos}[29\ \ 02.2] + \text{Sin}[39\ \ 59.0] * \text{Sin}[29\ \ 02.2]$$

$$\text{Cos [CZD]} = 0.34605 \longrightarrow \text{CZD } 69\ 45.3$$

4th Step: To Correct Sextant Altitude

Sext alt	20 20.0
I.E.	2.2 (-)
Obs. Alt	20 17.8
Dip	6.4 (-)
App alt	20 11.4
Corr.	2.6 (-)
T. alt	20 08.8
90°	90
T.Z.D.	69 51.2
C.Z.D.	69 45.3
Intercept	**5.9 A**

5th Step: To Find True Bearing

L.H.A.	087 04.6	A	0.043 S
Lat.	39 59.0 N	B	0.556 N
Dec.	29 02.2 N	C	0.513 N
		Az.	N 68.5 W
		T. Bg.	**291.5**

SOLVED EXAMPLE (2)

At Z.T. 1455 on November 15th ; 1990;

Ship was in D.R. position (40º 15`.0 S; 161º 00`.0 W).

- I. E. 1`.2 off the arc
- Ht. of Eye 12.7 m
- Ch. Error 3m 11s fast

Lower Limb of the Sun was observed as follows:

- Ch.Time 01h 51m 50s
- Sext.alt. 42º 15`.0

Find the elements of the position line by Intercept method.

Answer:

1st Step: To Adjust Time Of G.M.T.

Z.T.	1455 Nov. 15th
Z.N.	11 (+)
G.D.	0155 Nov. 16th

Ch. Time	1h 51m 50s
Ch. Error	03m 11s (-)
G.M.T.	1h 48m 39s Nov. 16th

2nd Step: To Extract L.H.A. & Dec.

GHA	198 49.9
Incr.	12 09.8
GHA	210 59.7
± Long.	161 00.0 (-)
LHA	49 59.7

Dec.	18 37.6 S
d. corr.	0.5 (+)
C. Dec.	18 38.1 S

3rd Step: To Calculate C.Z.D

Cos [CZD] = Cos [LHA]* Cos [Lat.]* Cos [Dec.] ± Sin[Lat.]* Sin[Dec.]

Cos [CZD] = Cos [49 59.7]* Cos [40 15.0]* Cos[18 38.1] + Sin[40 15.0]* Sin[18 38.1]

Cos [CZD] = 0.67139 $\longrightarrow$ CZD 47° 49`.6

4th Step: To Correct Sextant Altitude

Sext alt	42 15.0
I.E.	1.2 (+)
Obs. Alt	42 16.2
Dip	6.3 (-)
App alt	42 09.9
Corr.	15.2 (+)
T. alt	42 25.1
90°	90
T.Z.D.	47 34.9
C.Z.D.	47 49.6
Intercept	**14.7 T**

5th Step: To Find True Bearing

LHA	49 59.7
Lat.	40 15.0 S
Dec.	18 38.1 S

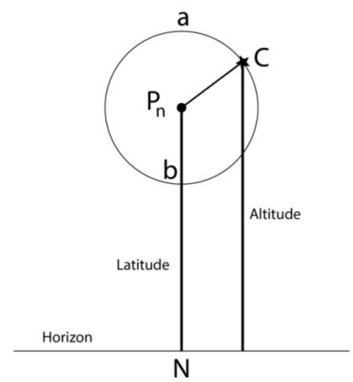
A	0.710 N
B	0.440 S
C	0.270 N
Az.	N 78.4 W
T. Bg.	**281.6**

Theory of Pole Star

Theory of Pole Star

A special method of finding latitude, available in the Northern Hemisphere, utilizes the fact that Polaris is less than 1° from the north celestial pole. As indicated before, the altitude of the elevated pole above the celestial horizon is equal to the latitude. Since Polaris is never far from the pole, its observed altitude, with suitable corrections, is the latitude

The nature of these corrections as tabulated in the *Nautical Almanac* is suggested by inspection of figure shown in which the circle represents the daily path of Polaris around the north celestial pole Pn , as seen by an observer on earth looking along the axis P_n P_s. The line a b represents a small portion of the observer`s meridian. Polaris is at upper transit at a and at lower transit at b.



Latitude is equal to the altitude *minus* the polar distance (P) when Polaris is at a and *plus* the polar distance when it is at b . When the star is at any point c , the Polaris correction is polar distance times the cosine of the local hour angle (i.e. correction = P. Cos LHA) . Thus the correction is a function of LHA of the star , and hence also of LHA♈ , insofar as the difference between these quantities (the SHA) can be considered constant

The Polaris correction tables included in the *Nautical Almanac Tables*, are based on the following formula:

Latitude - corrected sextant altitude

$$= -P \cos h + \tfrac{1}{2} P \sin P \sin^2 h \tan(\text{Latitude}).$$

Where: P = polar distance of Polaris = 90 – Dec.
h = local hour angle of Polaris = LHA♈ + SHA.

The value a_o which is a function of LHA♈ only , is the value of both terms of the above formula calculated for mean values of the SHA and Dec. of Polaris, for a mean latitude of 50° , and adjusted by the addition of a constant (58`.8).

The value a_1, which is a function of LHA♈ and latitude, is the excess of the value of the second term over its mean value for latitude 50°, increased by a constant (0`.6) to make it always positive.

The value a_2, which is a function of LHA♈ and date, is the correction to the first term for the variation of Polaris from its adopted mean position; it is increased by a constant (0`.6) to make it always positive.

The sum of the added constants is 1°, so that:

Latitude = corrected sextant altitude – 1° + a_0 + a_1 + a_2

The table at the top of each Polaris correction page is entered with LHA_Υ and the first correction (a_0) is taken out by a single interpolation. The second and third corrections (a_1 and a2 respectively) are taken from the double entry tables without interpolation, using the LHA_Υ column with the *latitude* for the second correction and with the *month* for the third correction.

POLARIS (POLE STAR) TABLES, 1990 275

FOR DETERMINING LATITUDE FROM SEXTANT ALTITUDE AND FOR AZIMUTH

L.H.A. ARIES	120°–129°	130°–139°	140°–149°	150°–159°	160°–169°	170°–179°	180°–189°	190°–199°	200°–209°	210°–219°	220°–229°	230°–239°
	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0 54·8	1 02·9	1 10·9	1 18·5	1 25·4	1 31·6	1 36·8	1 40·9	1 43·7	1 45·1	1 45·2	1 43·8
1	55·6	03·7	11·6	19·2	26·1	32·2	37·3	41·2	43·9	45·2	45·1	43·6
2	56·4	04·5	12·4	19·9	26·8	32·8	37·7	41·5	44·1	45·2	45·0	43·4
3	57·2	05·3	13·2	20·6	27·4	33·3	38·2	41·8	44·2	45·3	44·9	43·2
4	58·0	06·1	14·0	21·3	28·0	33·8	38·6	42·1	44·4	45·3	44·8	42·9
5	0 58·8	1 06·9	1 14·7	1 22·0	1 28·7	1 34·4	1 39·0	1 42·4	1 44·5	1 45·3	1 44·7	1 42·7
6	0 59·6	07·7	15·5	22·7	29·3	34·9	39·4	42·7	44·7	45·3	44·5	42·4
7	1 00·5	08·5	16·2	23·4	29·9	35·4	39·8	43·0	44·8	45·3	44·4	42·1
8	01·3	09·3	17·0	24·1	30·5	35·9	40·2	43·2	44·9	45·3	44·2	41·8
9	02·1	10·1	17·7	24·8	31·1	36·4	40·5	43·4	45·0	45·2	44·0	41·5
10	1 02·9	1 10·9	1 18·5	1 25·4	1 31·6	1 36·8	1 40·9	1 43·7	1 45·1	1 45·2	1 43·8	1 41·1
Lat.	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1
°	′	′	′	′	′	′	′	′	′	′	′	′
0	0·2	0·2	0·3	0·3	0·4	0·4	0·5	0·6	0·6	0·6	0·6	0·6
10	·3	·3	·3	·4	·4	·5	·5	·6	·6	·6	·6	·6
20	·3	·3	·4	·4	·4	·5	·5	·6	·6	·6	·6	·6
30	·4	·4	·4	·5	·5	·5	·6	·6	·6	·6	·6	·6
40	0·5	0·5	0·5	0·5	0·5	0·6	0·6	0·6	0·6	0·6	0·6	0·6
45	·5	·5	·5	·6	·6	·6	·6	·6	·6	·6	·6	·6
50	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6
55	·7	·7	·7	·7	·6	·6	·6	·6	·6	·6	·6	·6
60	·8	·8	·8	·7	·7	·7	·6	·6	·6	·6	·6	·6
62	0·8	0·8	0·8	0·8	0·7	0·7	0·7	0·6	0·6	0·6	0·6	0·6
64	·9	·9	·8	·8	·8	·7	·7	·6	·6	·6	·6	·6
66	0·9	0·9	0·9	·9	·8	·7	·7	·6	·6	·6	·6	·6
68	1·0	1·0	1·0	0·9	0·8	0·8	0·7	0·6	0·6	0·6	0·6	0·6
Month	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2
	′	′	′	′	′	′	′	′	′	′	′	′
Jan.	0·7	0·6	0·6	0·6	0·6	0·5	0·5	0·5	0·5	0·5	0·5	0·5
Feb.	·8	·8	·7	·7	·7	·6	·6	·5	·5	·5	·4	·4
Mar.	0·9	0·9	0·9	0·9	·8	·8	·7	·7	·6	·6	·5	·4
Apr.	1·0	1·0	1·0	1·0	0·9	0·9	0·9	0·8	0·8	0·7	0·6	0·6
May	0·9	1·0	1·0	1·0	1·0	1·0	1·0	0·9	0·9	·8	·8	·7

Solved Example:

At the morning twilight of August 12th; 1990;
Ship was in D.R. position (27º 15`.0 N; 146º 45`.0 W)

- Ch. Error 3m 10s slow
- I. E. 2`.0 off the arc
- Ht. of eye 13.5 m

The star *Polaris* was observed as:

- Ch. Time 02h 48m 11s
- Sext. Alt. 28º 14`.8

Calculate:

1) The true latitude of the observer.
2) The direction of the P.L.

Answer:

≈ L.M.T.	0500 Aug 12th
± Long. W/ E (+)	0947
G.D.	1447 Aug 12th

Ch. Time	02h 48m 11s
Ch. Error (+)	3m 10s
G.M.T.	14h 51m 21s Aug.12th

G.H.A. γ	170 45.7
Incr.	12 52.4
G.H.A. γ	183 38.1
± long (E/W) (-)	146 45.0
L.H.A. γ	36 53.1

Sext. alt.	28 14.8
IE (+)	2.0
Obs. alt.	28 16.8
Dip (-)	6.5
App. alt.	28 10.3
Corr. $^{\underline{n}}$ (-)	1.8
True alt.	28 08.5
a_o	0 12.3
a_1	0.6
a_2	0.3
(-) 1°	1
True Latitude	27 21.7 N

True Bearing 000º.0 → **P.L.** (090 º.0 / 270 º.0)

Preparation of Star Sights

PREPARATION FOR STAR SIGHTS

The work of obtaining a fixed position from star sights breaks down into a number of stages and operations that we recommend to be fulfilled in the following order:
(case of 3-stars is concerned)

1) Preparation for observations in twilight.
2) Taking star sights.
3) Working sights
    a. Computations.
    b. Plotting Sights (on a paper).
    c. Triangle of Errors.
    d. Obtaining the most probable observed position.

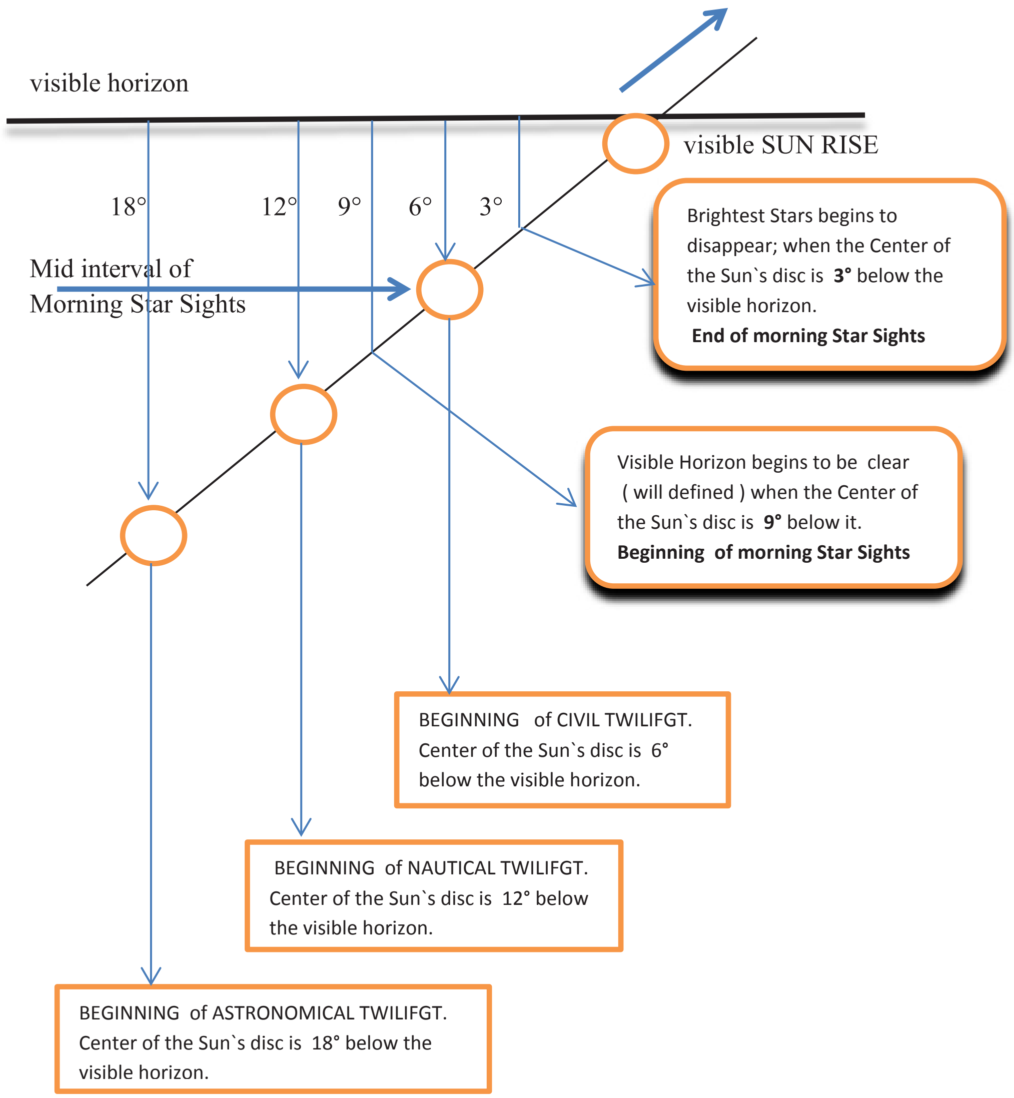
Preparation for observing stars in duration of twilight

Practically , at the duration of the *evening twilight*, the bright stars can be observed when the center's disk of Sun reaches about 3° below the western horizon , while it will be difficult to observe the stars when center's disk of Sun reaches about 9° below , since the horizon becomes hazy (not clearly defined).

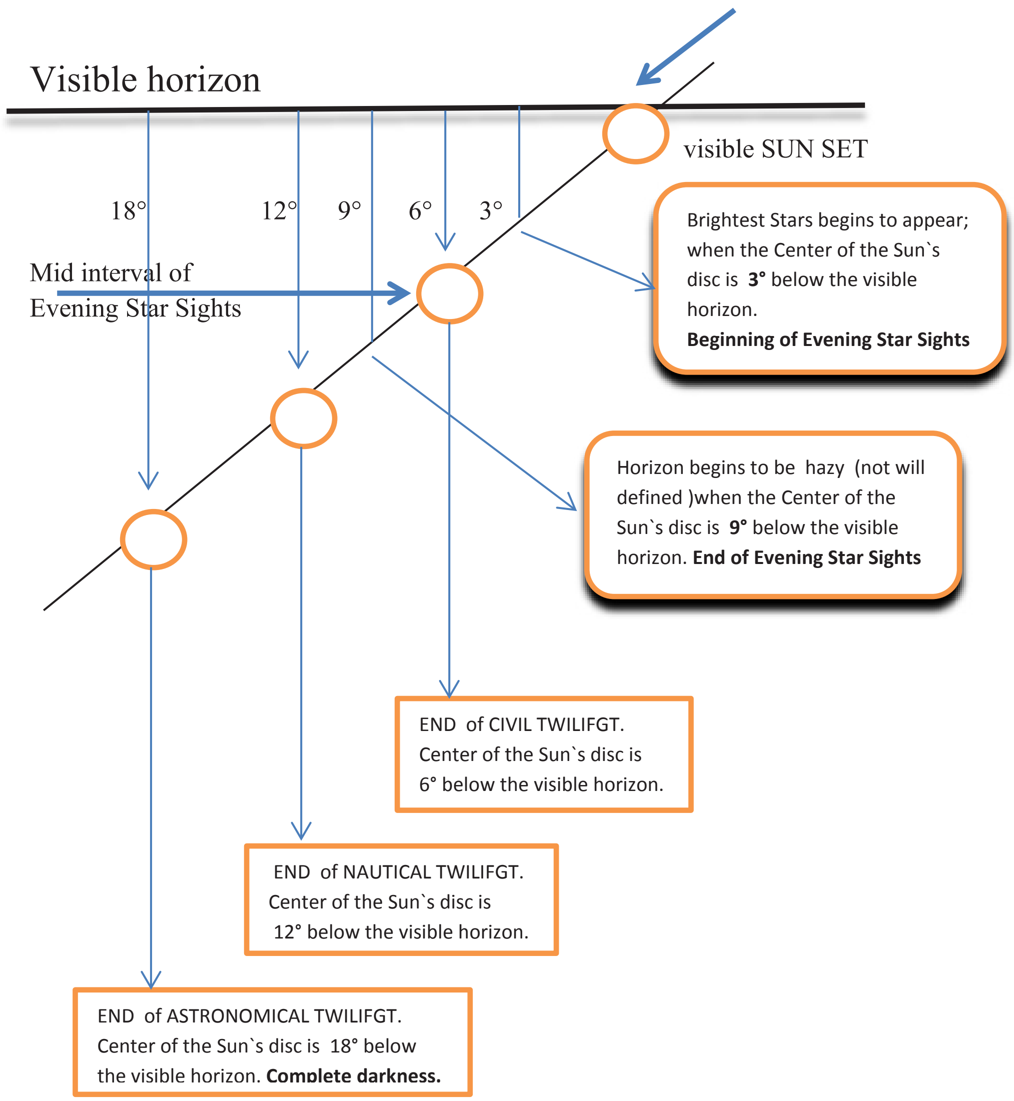
Reversely, at the duration of the morning twilight, the visible horizon starts to be defined when the center's disk of Sun reaches 9° below the eastern horizon, and when it reaches 3° below, the bright stars begins to disappear.

See following diagrams for *Morning Twilight* and *Evening Twilight.*

MORNING TWILIGHT



EVENING TWILIGHT



This indicates that the times of the ***civil twilight*** tabulated in the *Nautical Almanac* are actually the middle time of taking star sights. So, to prepare for evening or morning star sights we proceed as follows:

1. Extract DR_1 position, corresponding to the assumed ZT ,from the chart.
2. Calculate GD = ZT ± ZN
3. Calculate GMT_1 of the next civil twilight to the nearest minute. (1st approximation)
4. Make run through the interval ($\Delta T = GMT_1 - GD$) to obtain the corresponding position DR_2.
5. Calculate GMT_2 of the next civil twilight to the nearest minute. (2nd approximation.)
6. Make run through the interval ($\Delta T = GMT_2 - GMT_1$) to obtain the corresponding position DR_3.
7. Calculate LHAϒ at GMT_2, using DR_3 Long.
8. By the knowledge of **DR_3 Lat. & LHAϒ** ; use the *SIGHT REDUCTION TABLES FOR AIR NAVIGATION* (vol. 1) or any other device (star glob / rude star identifier) , to select combinations of 3- suitable stars regarding the following considerations :

Selection of stars for a fix

In making a choice, the following three things must be considered, listed from highest priority to least priority.

First priority: the azimuth differences between the stars should be sufficient to give a reliable fix. The ideal azimuth spread would be for the bearings of the stars to differ by 120°.

Second priority: the stars should be at altitudes between 15° and 70° (where possible , with approximately the same altitude) , since unusual refraction can introduce large errors in low altitude sights, and accurate sights at very high altitudes are difficult to obtain.

Third priority: the magnitude of the star. Obviously first magnitude stars are easier to see and to shoot while the horizon is still clearly defined.

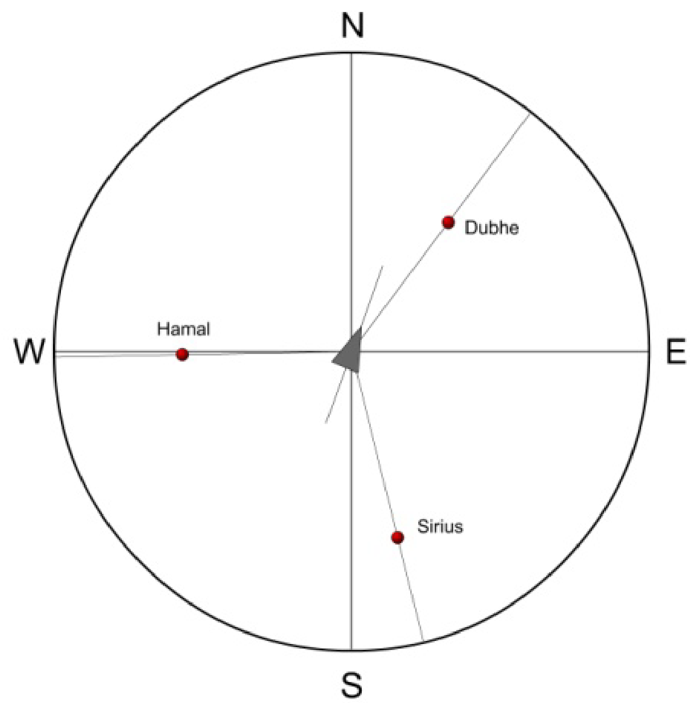
The selected stars are arranged in a tabular format similar to that below:

Star name			
Az.			
Alt.			
Mag.			

Make also a rough sketch showing the bearings relative to the course of the ship; this will make identification easier.

As an example this done as follows assuming True Course 020°

Star name	*Dubhe*	*Sirius*	*Hamal*
Az.	037	166	269
Alt.	41	32	39
Mag.	2.0	- 1.6	2.2



Note:

SIGHT REDUCTION TABLES FOR AIR NAVIGATION (AP 3270, vol. 1) solves the problem by giving the names of 7-stars suitable for observation; three of them are marked with an asterisk to distinguish them as the perfect 3-stars to be observed regarding the priorities mentioned before. The names of first-magnitude stars are given in capital letters.

LAT 40°N

LHA ♈	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	♦Dubhe		REGULUS		PROCYON		♦SIRIUS		RIGEL		ALDEBARAN		♦Mirfak	
90	41 02	037	29 13	099	48 50	141	32 23	167	40 36	195	60 04	224	60 54	303
91	41 30	037	29 58	100	49 19	142	32 32	169	40 23	196	59 32	226	60 15	303
92	41 58	037	30 43	100	49 47	144	32 41	170	40 10	198	58 58	227	59 36	303
93	42 26	038	31 28	101	50 13	145	32 49	171	39 55	199	58 24	229	58 58	303
94	42 54	038	32 14	102	50 39	147	32 56	172	39 40	200	57 49	230	58 19	303
95	43 22	038	32 58	103	51 04	148	33 02	173	39 23	201	57 13	232	57 40	303
96	43 50	038	33 43	103	51 28	149	33 07	174	39 06	203	56 37	233	57 01	303
97	44 18	038	34 28	104	51 51	151	33 11	175	38 48	204	56 00	234	56 23	303

Solved Example

At Z.T. 0005 January 2nd ; 1990.

Ship was in DR Position (32° 45`.0 S; 173° 20`.0 E)

- Steaming Speed 19.5 K
- Steering compass course 330°.0
- Variation 3°.0 E 1980 (6` E)
- Deviation 1°.0 W

Calculate:

- True course to steer.
- GMT of morning civil twilight (to the nearest minute)
- DR position at morning civil twilight
- Regarding tables of Air Navigation; Name the 3-selected stars recommended and their predicted altitudes & bearings (to the nearest degree).

Answer:

1) To find True Course to Steer

$Var._{1990}=Var._{1980}$ + (6`x10) =3°.0E+1°.0=4°.0E

Variation	4.0 E
deviation	1.0 W
C. Error	3.0 E

C. Co to steer	330.0
C. Error	3.0 E
T.Co.to steer	333.0

2) To find G.M.T. of morning civil twilight

Z.T.	0005 Jan 2nd
Z.N. (-)	12
G.D.	1205 Jan 1st

1st Approximation

L.M.T.	0436 Jan 2nd
Lat. C^n (-)	8
L.M.T.	0428 Jan 2nd
± Long. w/ E	1133 (-)
$G.M.T._1$	1655 Jan 1st
G.D.	1205 Jan 1st
Interval	0450

Distance Run = (04h 50m) x 19.5 = **94.3 M**

True Course to steer **333.0**

d. Lat.	**dep.**	Mean latitude	**d. Long.**
84.0 N	42.8 W	(32 03.0)	50.5 W

DR_1 Position	Lat.	32 45.0 S	Long.	173 20.0 E
	d. Lat.	01 24.0 N	d. Long.	0 50.5 W
DR_2 Position	Lat.	31 21.0 S	Long.	172 29.5 E

2nd Approximation

L.M.T.	0436 Jan 2nd
Lat. Cn (-)	4
L.M.T.	0432 Jan 2nd
± Long. w/ E	1130 (-)
G.M.T.2	1702 Jan 1st
G.M.T.1	1655 Jan 1st
Interval	0007 (+)

Distance Run = (00h 07m) x 19.5 = **2.3 M**

True Course to steer **333.0**

d. Lat.	**dep.**	Mean latitude	**d. Long.**
2.0 N	1.0 W	(31 20)	1.2 W

DR_2 Position	Lat.	31 21.0 S	Long.	172 29.5 E
	d. Lat.	2.0 N	d. Long.	1.2 W
DR_3 Position	Lat.	31 19.0 S	Long.	172 28.3 E

3) *To Extract the 3-Recommended Stars*

G. M.T. 17h 02m 00s Jan 1st →

G.H.A. γ	356 05.1
Incr.	30.1
G.H.A. γ	356 35.2
± Long. E/W	172 28.3 E
L.H.A. γ	169 03.5

Regarding tables of Air Navigation;
and the arguments

DR Latitude ≈ 31 S

L.H.A. γ ≈ 169

LAT 31°S

LHA ♈	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	PROCYON		REGULUS		♦Suhail		ACRUX		♦ACHERNAR		RIGEL		♦BETELGEUSE	
90	46 39	038	16 32	065	51 04	122	24 26	150	38 44	219	64 54	333	51 35	358
91	47 11	037	17 18	064	51 47	122	24 52	150	38 11	219	64 29	331	51 32	357
92	47 41	035	18 04	063	52 31	122	25 17	150	37 39	219	64 03	329	51 29	355
93	48 10	034	18 50	063	53 14	122	25 43	150	37 06	219	63 36	327	51 24	354
94	48 38	033	19 35	062	53 58	123	26 09	150	36 34	219	63 07	325	51 17	352
95	49 05	031	20 21	061	54 41	123	26 35	150	36 01	219	62 37	323	51 09	350
96	49 31	030	21 06	061	55 24	123	27 01	150	35 29	219	62 05	321	51 00	349
97	49 57	028	21 50	060	56 07	123	27 27	149	34 56	219	61 32	319	50 49	347
98	50 20	027	22 35	059	56 50	123	27 53	149	34 24	219	60 58	318	50 37	346
99	50 43	026	23 19	059	57 33	123	28 19	149	33 52	219	60 23	316	50 24	344

4) *The Stars recommended are:*

	Star Name	Altitude	True Bearing
1	*Antares*	22.5	108
2	*Canopus*	34	224
3	*Regulus*	44	337

LHA ♈	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
157	46 50	353	40 27	026	44 28	074	52 42	158	41 27	225	37 44	272	35 58	305
158	46 44	352	40 49	025	45 18	073	53 01	159	40 50	225	36 53	272	35 15	304
159	46 35	350	41 10	024	46 07	073	53 19	159	40 14	225	36 01	271	34 32	303
160	46 26	349	41 31	023	46 56	072	53 37	160	39 37	225	35 10	271	33 49	302
161	46 16	348	41 50	022	47 45	071	53 54	161	39 01	225	34 18	270	33 05	301
162	46 04	346	42 08	020	48 33	070	54 11	161	38 25	225	33 27	270	32 21	300
163	45 51	345	42 26	019	49 22	069	54 28	162	37 49	225	32 36	269	31 36	300
164	45 37	343	42 42	018	50 10	069	54 44	162	37 12	225	31 44	269	30 51	299
	ARCTURUS		♦ANTARES		ACRUX		♦CANOPUS		SIRIUS		PROCYON		♦REGULUS	
165	21 14	050	19 14	110	54 59	163	36 36	225	30 53	268	30 06	298	45 22	342
166	21 53	049	20 03	110	55 14	164	36 00	225	30 01	268	29 21	297	45 05	341
167	22 32	048	20 51	109	55 28	164	35 24	225	29 10	267	28 35	297	44 48	339
168	23 10	048	21 40	109	55 41	165	34 47	225	28 19	267	27 49	296	44 [illegible]	338
169	23 48	047	22 29	108	55 54	166	34 11	224	27 27	266	27 02	295	44 09	337
170	24 25	046	23 18	108	56 07	166	33 35	224	26 36	266	26 16	294	43 49	336
171	25 02	045	24 07	107	56 18	167	33 00	224	25 45	265	25 29	294	43 27	334
172	25 39	045	24 56	107	56 29	168	32 24	224	24 53	265	24 41	293	43 04	333
173	26 14	044	25 45	107	56 40	169	31 48	224	24 02	264	23 54	292	42 40	332
174	26 50	043	26 34	106	56 50	169	31 12	224	23 11	264	23 06	292	42 16	331
175	27 24	042	27 24	106	56 59	170	30 37	224	22 20	263	22 18	291	41 50	329
176	27 59	041	28 13	106	57 07	171	30 01	224	21 29	263	21 30	291	41 23	328
177	28 32	040	29 03	105	57 15	172	29 26	223	20 38	262	20 42	290	40 56	327
178	29 05	039	29 53	105	57 22	173	28 50	223	19 47	262	19 54	289	40 27	326
179	29 38	039	30 42	104	57 28	173	28 15	223	18 56	261	19 05	289	39 58	325

Simultaneous Star Sights

INTRODUCTION

The work of obtaining a fixed position from two star sights breaks down into a number of stages and operations that we recommend to be fulfilled in the following order:

A. Preparation for observations in twilight.
B. Taking star sights.
C. Working sights
    a) Computations.
    b) Plotting Sights (on a paper).
    c) Obtaining the observed position.

The process A was explained in the previous lecture (5) in details, we start this lecture by process B.

B. Taking star sights

1. Before taking observations :
    a) When possible , check the sextant for side error
    b) When possible, take the index error before and after sights.
    c) If a deck watch or other timepiece is available and suitable for observations, compare it with the chronometer.
    d) Make sure that the minute and second hands of the deck watch are, lined up, so that there can be no possibility of an error in the reading of the minute hand. Time should be read to the nearest second.
2. Between 10 to 15 minutes prior to commencement of observations, take the sextant to the site of observations.
3. Measure a round of 3 (or 5) altitudes of each star and note time by watch or chronometer. It is more convenient to take these observations with an assistant.
4. Observe stars as early as possible at evening twilight and as late as possible at morning twilight. The horizon will then be clearest.
5. The brighter star is observed in the evening at the very beginning of twilight; the fainter stars in the morning.
6. In the morning and evening twilight, start observations of stars above the eastern horizon first.
7. In clear weather, take observations from the highest convenient position.
8. In fog, haze or mist, take observations from the lowest convenient position.
9. When the ship is rolling heavily, errors due to rapidly changing dip may be reduced, and more accurate observations obtained, by observing from a position close to the center line of the ship.
10. Having brought the star to the horizon, always swing the sextant a few degrees each side of the vertical plane to make the body appear to describe the arc of a circle. This arc should then be raised or lowered by means of the micrometer drum, until just touches the horizon.
11. Record the true course, speed of vessel, air temperature and pressure.

C. *Working sights*

a) Computations

i. Using the recorded time ZT and log reading, take DR position from map to within 0`.1.

ii. For each of the three stars:

- Compute the mean sextant altitude and the mean chronometer time.
- Compute the exact instants of GMT and date.
- Extract the GHA & Dec. from the *Nautical Almanac Tables*.
- Compute LHA = GHA ± DR Long. E/W
- Compute CZD using cosine formula; by the knowledge of LHA, DR Latitude and Dec.
- Compute True Bearing (T. Bg.) using A/B/C tables.
- Correct the mean sextant altitude to get true altitude, hence TZD, by applying the rule: TZD = 90° - true altitude.
- Apply the equation : Intercept (n) = TZD – CZD ; and denote it Away or Towards according to the following :
  a) denoted Away (A) if ; TZD > CZD
  b) denoted Towards (T) if ; TZD < CZD

b) Plotting Position Lines

To plot a PL at a subsequent or earlier time we first calculate the distance run to transfer as follows:

1. Calculate the interval of time ΔT_i = Required GMT – Actual GMT $_i$
2. Calculate distance run $d_i = \Delta T_i . V$

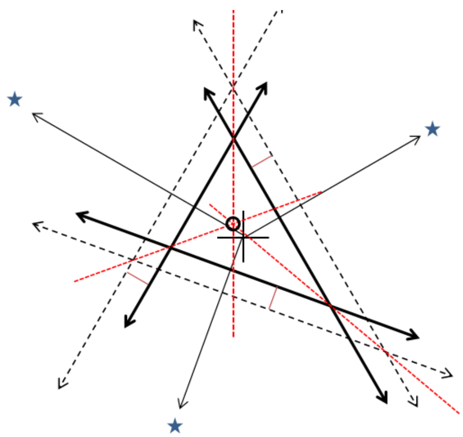
Steps:

- From the DR position lay off the true course.
- Measure the distance run d_i on line of true course and mark a point (i).
- From the point (i), lay off the Az. $_{(i)}$
- Measure the Intercept n $_{(i)}$ on the line of Az. $_{(i)}$, then construct a perpendicular to Az. $_{(i)}$ at the end point of measured intercept n $_{(i)}$.

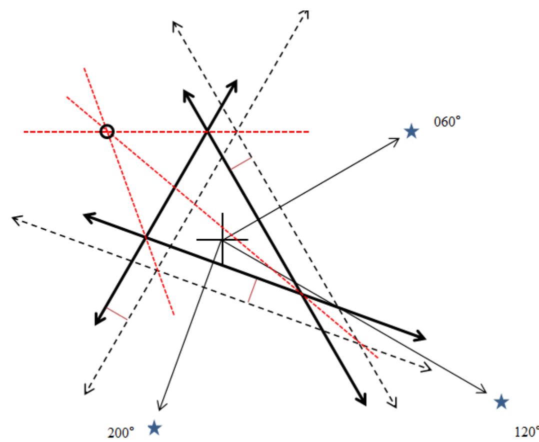
This perpendicular is actually the transferred position line.

c) Obtaining the most probable observed position

Once you finish these steps, there will be a triangle named *triangle of errors*.
The most probable observed position (*MPOP*) may be situated inside or outside this triangle according to the distribution of the bearings of the stars on the circle of the horizon. *MPOP* will be inside the *triangle of errors* in case of distribution all-round, and outside in case of being subtended in only one half (180°). To solve this problem, do the following steps:



Stars are distributed all-round the horizon.
MPOP will be situated in the triangle of errors



Stars are distributed in one half of the horizon.
MPOP will be situated out of the triangle of errors

- Transfer every PL in the direction of its bearing by a chosen suitable distance (fixed distance for all).Another similar triangle is obtained.
- Join the similar vertices of the two triangles. The point of intersection is the most probable observed position MPOP, at the time required (i.e. time corresponding to the DR used in solving sights).
- Lay off a perpendicular from fixed position to DR Lat. This is d. Lat.
- Lay off a perpendicular from fixed position to DR Long. This is departure.
- Convert departure into d. Long. Where d. Long. $= \frac{dep}{\cos DR\ lat}$.
- Add d. Lat. & d. Long. to the DR (Lat. ; Long.) to get the coordinates of the fixed position.

Solved Example (1)

Evening twilight on December 10th; 1990.
Ship was in DR Position (38° 39`.0 S; 170° 40`.0 W)
Where:

- Steaming Speed 17.4 K
- Steering compass course 310°.0
- Variation 4°.5 E 1985 (6` E)
- Deviation 1°.5 E
- Ch. Error 6m 10s slow

The following are the results of solving 3-simultaneous star sights:

		Elements of P.L.	
Star Name	Ch.Time	True Bearing	Intercept
Menkar	07h 10m 00s	038°.0	1.5 T
Adhara	07h 15m 05s	290°.0	2.0 T
Atria	07h 20m 10s	199°.0	1.0 A

Find the most probable observed position at G.M.T. **07h 20m 00s Dec. 11th**

Answer:

To find True Course to Steer

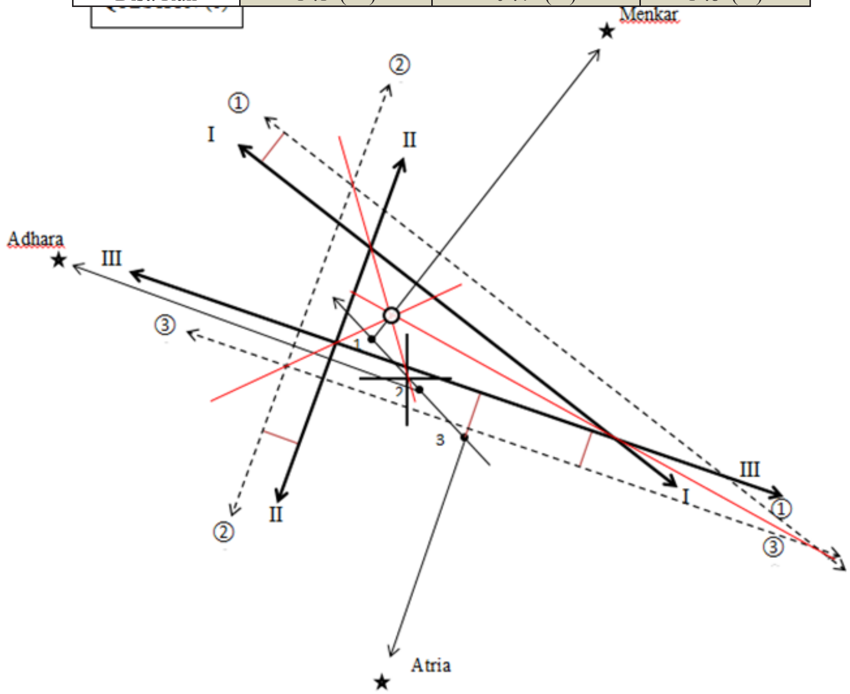
Var. (1990) = 4°.5 E + 0°.5 = 5°.0 E

Variation	5°.0 E
deviation	1°.5 E
C. Error	6°.5 E

C. Co to steer	310°.0
C. Error (+)	6°.5
T.Co.to steer	**316°.5**

Calculations of Run:

	Menkar	*Adhara*	*Atria*
Ch. Time Ch. Error (+)	7h 10m 00s 6m 10s	7h 15m 05s 6m 10s	7h 20m 10s 6m 10s
G.M.T. R.G.M.T.	7h 16m 10s 7h 20m 00s	7h 21m 15s 7h 20m 00s	7h 26m 20s 7h 20m 00s
Interval	0h 03m 50s (+)	0h 01m 15s (-)	0h 06m 20s
Dist. Run	1`.1 (+)	0`.4 (-)	1`.8 (-)



Plotting:

DR Position	Lat. d. Lat.	38 39.0 S 1.3 N	Long. d. Long.	170 40.0 W 0.5 W
MPO Position	**Lat.**	**38 37.7 S**	**Long.**	**170 40.5 W**

Solved Example (2)

Morning twilight on August 18th
Ship was in DR Position (40° 00`.0 S; 162° 35`.0 E)

Steaming Speed 17.8 K
Steering compass course 037°.5
Variation (1975) 0°.5 W (decreasing 4` annually)
Deviation 3°.5E
Ch. Error 1m 45s slow

The following are the results of solving 3-simultaneous star sights:

		Elements of P.L.	
Star Name	Ch. Time	True Bearing	Intercept
Aldebaran	07h 20m 10s	009°.0	1`.1 T
Sirius	07h 24m 30s	068°.0	2`.0 A
Avior	07h 28m 15s	139°.0	1`.5A

Find the most probable observed position at G.M.T. 19h 30m 00s Aug 17th .

Answer:

To find True Course to Steer

Var. (1990) = 0°.5 W -1°.0 = 0°.5E

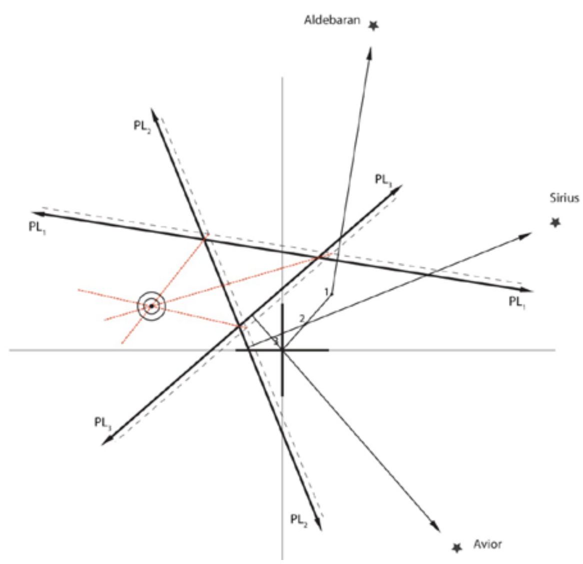
Variation	0°.5E
deviation	3°.5E
C. Error	4°.0 E

C. Co to steer	037°.5
C. Error (+)	4°.0
T.Co.to steer	**041°.5**

Calculations of Run:

	Aldebaranl	*Sirius*	*Avior*
Ch. Time Ch. Error (+)	19h 20m 10s 1m 45s	19h 24m 30s 1m 45s	19h 28m 15s 1m 45s
G.M.T. R.G.M.T.	19h 21m 55s 19h 30m 00s	19h 26m 15s 19h 30m 00s	19h 30m 00s 19h 30m 00s
Interval	0h 08m 05s (+)	0h 03m 45s (+)	0h 00m 00s
Dist. Run	2`.4 (+)	1`.1 (+)	0`.0

Plotting



DR Position	Lat. d. Lat.	40 00.0 S 01.2 N	Long. d. Long.	162 35.0 E 06.0 W
MPO Position	Lat.	39 58.8 S	Long.	162 29.0 E

Long Run Sights

ROUTINE AND PRACTICAL SUGGESTIONS FOR OBTAINING A RUNNING FIX of THE SUN (Long Run Sights)

A. *Taking sights*

1. Before starting observations:
   a) Prepare sextant for taking sun altitudes, make a rapid check of sextant errors, and take up a position for observations 10 to15 minutes ahead of time, but do not keep the instrument in the sun.
   b) Compare deck watch (or other timepiece) with chronometer, or stop watch with chronometer if the former is used.
2. Determine the index correction with a check
3. Take a series of 3 (or 5) sun altitudes and note the time for each one (using watch or chronometer): it is common practice to measure the altitude of the lower limb of the sun.
4. When measuring the mean of the altitudes (or after the measurement), note and record ZT, log. lr ,True course , ship's speed , height of observer's eye , temperature and pressure of air (if $h < 30°$). Take compass bearing of the sun (C. $Bg._1$)

B. *Working first sight*

1. Using ZT and log take from chart DR_1 (Lat.; Long) to within 0`.1.
2. Compute the arithmetic mean of the sextant readings and DWT^s.
3. Correct mean reading of sextant with corrections and obtain TZD.
4. Compute the accurate UT (GMT)
5. Obtain LHA and Dec. from nautical almanac.
6. Compute CZD and TBg_1 from formulas and obtain $Intercept_1$.
7. After working the sights, again take the sun bearing (C $Bg._2$) and note
8. Take measure to enhance accuracy of dead reckoning between observations:
   a) Check corrections of compass, distance log, current and drift.
   b) Obtain the ship's run S in three ways and take the most reliable one or the arithmetic mean;
   c) Do the plotting on a large scale chart; if no such chart is available or the run is very long, obtain DR_2 by rules of sailing.

C. *Second Set of Sights and their Working*

1. If visibility of the sun or horizon deteriorates (increased cloud cover, approach of fog, etc.) or if there is any other insistent necessity, the second set of observations are carried out without waiting for a computed instant.

2. Under ordinary conditions, the second set of observations is executed after the specified time interval, like the first set.

3. When measuring the mean of the altitudes, note ZT and log. If conditions have changed, obtain other data as well.

4. Working the second set of observations is done in a similar fashion to that for the first set, but with DR_2 obtained at the second mean instant.

Solved Example

Z.T. 1312 Nov. 13th ; 1990
Ship was in DR position (34˚ 53`.0 S; 32˚ 25`.0 W);
Ship was steaming as follows:

Compass course to steer	344˚.0
Variation	2˚.5 E 1980 (3` W)
Deviation	5˚.0 W
Speed	18.0 k
Chronometer error	01m 19s slow
Index error	2`.1 off arc
Height of eye	10.5 m

1st sun sight at Ch. Time 03h 12m 05s when solved gave:
Sextant alt. 65˚ 25`.5 (L.L)

2nd sun sight at Ch. Time 05h 20m 31s when observed gave:
Sextant alt. 41° 20`.0 (L.L)

Find the observed position at the time of the 2nd sight.

Answer:

Solution of the 1st Sun sight:

1st Step: To Find G.M.T

Z.T.1	1312 Nov 13
Z.N. (+)	2
G.D.1	1512 Nov 13

Ch. Time 1	03 12 05
Ch. Error (+)	01 19
G.M.T. 1	15 13 24 Nov 13th

2nd Step: To Find L.H.A. & Dec.

GHA	48 55.6	Dec	18 00.1 S
Incr.	3 21.0	d. corrn (+)	0.2
GHA	52 16.6	**D. Dec.**	18 00.3 S
Long (-)	32 25.0		
LHA	**19 51.6**		

3rd Step: To Calculate C.Z.D

Cos [CZD] = Cos [LHA]* Cos[Lat.]* Cos[Dec.] ± Sin[Lat.]* Sin[Dec.]

Cos[CZD] = Cos[19 51.6]* Cos[34 53.0]* Cos[18 00.3] + Sin[34 53.0]* Sin[18 00.3]

Cos [CZD] = 0.91052 $\longrightarrow$ CZD 24 25.3

4th Step: To Correct Sextant Altitude

Sext alt	65 25.5
I.E.	2.1 (+)
Obs. Alt	65 27.6
Dip	5.7 (-)
App alt	65 21.9
Corr.	15.8 (+)
T. alt	65 37.7
90°	90
T.Z.D.	24 22.3
C.Z.D.	24 25.3
Intercept	3.0 T

5th Step: To Find True Bearing

L.H.A.	19 51.6
Lat.	34 53.0 S
Dec.	18 00.3 S

A	1.930 N
B	0.957 S
C	0.973 N
Az.	N 51.4 W
T. Bg.	308.6

To find True Course to Steer

Var. (1990) = 2.5 E - 0.5 = 2.0 E

Variation	2.0 E
deviation	5.0 W
C. Error	3.0 W

C. Co to steer	344.0
C. Error (-)	3.0 W
T.Co.to steer	341.0

To Find 2nd DR Position:

Z.T.2	
Z.N.	
G.D.2	

Ch. Time 2	05 20 31
Ch. Error +	01 19
G.M.T. 2	17 21 50

G.M.T. 2	17 21 50
G.M.T. 1	15 13 24
Interval	02 08 26

Distance Run = (02 08 26) x 18.0 = 38.5 M

	distance	True Co.	d. Lat.	Dep.
Run	38.5	341.0	36.4 N	12.5 W
1st sight	3.0 T	308.6	1.9 N	2.3 W
			38.3 N	14.8 W

d. Long. = dep. / cos (m.Lat.) = 14.8 / cos (34°.6)
d. Long. = 18.0 W

DR1 Position	Lat.	34 53.0 S	Long.	32 25.0 W
	d. Lat.	38.3 N	d. Long.	18.0 W
DR2 Position	Lat.	34 14.7 S	Long.	32 43.0 W

Solution of 2nd Sun Sight

G.M.T. 2 17 21 50 Nov 13th
DR2 Position Lat. 34 14.7 S Long. 32 43.0 W

2nd Step: To Find L.H.A. & Dec.

GHA	78 55.5	Dec	18 01.4 S
Incr.	5 27.5	d. corrn (+)	0.3
GHA	84 23.0	C. Dec.	18 01.7 S
Long (-)	32 43.0		
LHA	51 40.0		

3rd Step: To Calculate C.Z.D

Cos [CZD] = Cos [LHA]* Cos[Lat.]* Cos[Dec.] ± Sin[Lat.]* Sin[Dec.]

Cos[CZD] = Cos[51 40.0]* Cos[34 14.7]* Cos[18 01.7] + Sin[34 14.7]* Sin[18 01.7]

Cos [CZD] = 0.16670 ⟶ CZD 48 34.2

4th Step: To Correct Sextant Altitude

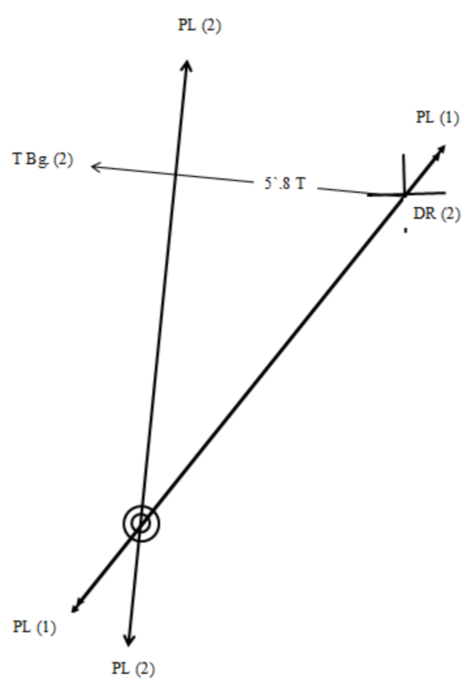
Sext alt	41 20.0
I.E.	2.1 (+)
Obs. Alt	41 22.1
Dip	5.7 (-)
App alt	41 16.4
Corr.	15.2 (+)
T. alt	41 31.6
90°	90
T.Z.D.	48 28.4
C.Z.D.	48 34.2
Intercept	5.8 T

5th Step: To Find True Bearing

L.H.A.	51 40.0
Lat.	34 14.7 S
Dec.	18 01.7 S

A	0.538 N
B	0.415 S
C	0.123 N
Az.	N 84.2 W
T. Bg.	275.8

Plotting:



From Plotting Sheet:

DR$_2$ Position	Lat. d. Lat.	34 14.7 S 08.4 S	Long. d. Long.	32 43.0 W 08.1 W
Fix. Position	Lat.	34 23.1 S	Long.	32 51.1 W

Noon Sight of the Sun

Noon Sight of Sun

Introduction

The chief engineer is responsible for preparing the noon report and it is sent by the master to the company and shore management at a fixed time on daily basis (normally it is sent during noon; hence it's called noon report).

Deck officer (normally 2nd officer) assists the chief engineer in providing the required data, which are used to complete the noon report. The master has the overall responsibility to ensure that the noon report is sent to the company on time.

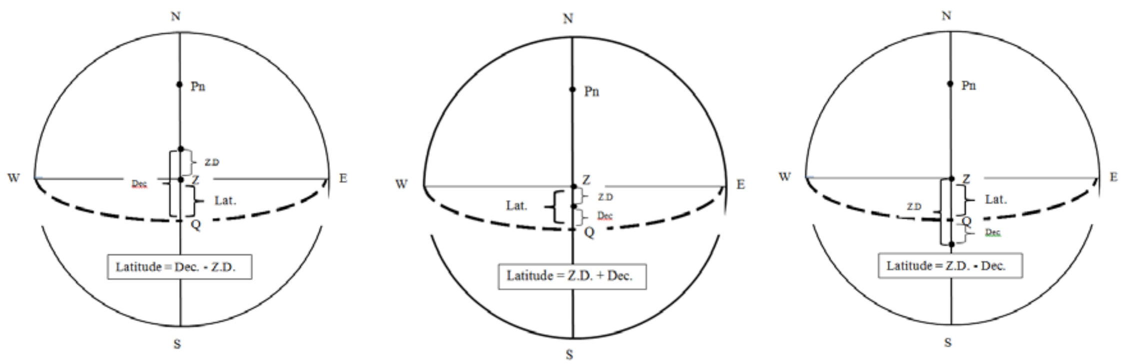
Below is a general overview of the content of a noon report and how they are recorded:

- Ship's Name: Name or Call sign of the ship
- Voyage number: Every noon report comes with the current voyage number where the ship is plying
- Date of the report: Date of noon report
- Time of the report: Time of noon report. Chief engineer and ship staff must ensure that the noon report is sent daily at same time
- *Position of the ship : The position of ship taken from GPS of the ship in Latitude and Longitude at the time of noon (or time of report preparation)*
- Average speed done since last submitted noon report in knots: The average speed is calculated out from the net speed of the ship in knots since last noon report
- Propeller Slip: The total revolutions of the propeller from noon to noon is obtained using revolution counter. The engine distance can be calculated using the pitch of the propeller provided by the manufacturer.
- Average RPM: Average RPM Of the propulsion engine/ engines
- Wind Direction and wind force: The force and direction of the wind
- Sea and swell condition: General sea and swell condition at the time of report preparation
- Distance to Next Port of call/ destination: The distance which the ship needs to cover to reach the next port
- *Estimated Time of Arrival: The Deck officer will calculate the ETA for the next port of call*
- R.O.B : Following "Remaining on board" are prepared by the chief engineer where he/she takes account of either all Fuel oil/lube oil/water present on board ship or excluding the oil/water which are in the daily consumption or service tanks to keep a safe margin
    - Fresh Water in MT
    - Fuel Oil in MT
    - LSFO in MT
    - Diesel oil in MT
    - LSDO in MT
    - Lube oil for ME in MT
    - Lube oil for Generator in MT
    - Hydraulic oil in MT

Meridian Altitude:

For a heavenly body when crossing the upper meridian, its meridian altitude (M. Alt.) is denoted N or S as the nearest cardinal point. The meridian zenith distance (MZD= 90° - M. Alt.) is denoted S or N respectively.

A) Regarding the figures below of the celestial sphere projected on the horizon plane, we conclude that the true latitude can be obtained by applying suitable equation of the following:



The general relation:

True Latitude = T.M.Z.D. +/~ Dec.

- If T.M.Z.D. and Dec. have same names add and give the Latitude that name.
- If T.M.Z.D. and Dec. have different names subtract and give the Latitude the name of the greatest.

Note:
The LMT of meridian passage of the sun is given in the daily pages of the *Nautical Almanac Tables*. So to prepare for noon sight we proceed as follows:

1. Extract DR_1 position, corresponding to the assumed ZT, from the chart.
2. Calculate GD = ZT ± ZN
3. Calculate GMT_1 of the meridian passage to the nearest minute. (1st approximation)

LMT		
± Long. $_1$W/E		
GMT $_1$	→	This is the 1st approximate GMT

4. Make run through the interval ($\Delta T = GMT_1$ - GD) to obtain the corresponding position DR_2.
5. Calculate GMT_2 of the meridian passage the nearest minute. (2nd approximation.)

LMT		
± Long. $_2$ W/E		
GMT $_1$	→	This is the 2nd approximate GMT

6. Make run through the interval ($\Delta T = GMT_2 - GMT_1$) to obtain the corresponding position DR_3.

To find Accurate GMT

7. Since the LHA of the sun is 360° / 000° on the upper meridian of the observer; we obtain the accurate GMT of this instant applying the following steps:

LHA ± Long. $_{3}$W/E	360° 00`.0
Total GHA Tab. GHA (-)	
Increment	
GMT	

Extracted from daily page, (just less than total GHA). This give hour of GMT

Apply the relation (Incr. / 15°) This gives minutes and seconds of GMT

To Find True Latitude

8. Calculate Dec. of the sun at GMT_2.
9. Correct sext. alt. as common, then apply the general relation;

True Latitude = T.M.Z.D. +/~ Dec.

Sext. mer. alt. IE (±)	
Obs. mer. alt. Dip (-)	
App. mer. alt. Corr^{n} (+)	
True mer. alt. 90 (~)	
TMZD C. Dec. (~)	
True Latitude	

Solved Example

At Z.T. 0830; August 12th ; 1990
Ship was in D.R. position (40º 45`.0 S; 159º 42`.0 E)

- Ch. Error 1m 40s slow
- I.E 1`.5 on the arc
- Ht. of eye 14.9 m
- C. Co. to Steer 115º
- Var. 1°.5 W; 1980 (6` E)
- Dev. 1°.5 W
- Speed 19.5 knots

Calculate the following:

1) G.M.T. of meridian passage of the **True Sun** to the nearest second.
2) Ch. Time of the same phenomena.
3) The true latitude of the observer; if the sextant meridian altitude of the lower limb of the sun was observed 33° 40`.0 due North.

Answer:

T0 Correct Compass Course to Steer

Var. (1990) = 1.5 W - 1.0 = 0.5 W

Variation	0.5 W
deviation	1.5 W
C. Error	2.0 W

C. Co to steer	115.0
C. Error (+)	2.0 W
T.Co.to steer	**113.0**

To find G.M.T. of Noon:

Z.T.	0830 Aug. 12th
Z.N. (-)	11
G.D.	2130 Aug. 11th

1st Approximation

L.M.T.	1205 Aug. 12th
± Long. w/ E (-)	1039
G.M.T.1	0126 Aug. 12th
G.D.	2130 Aug. 11th
Interval	0356

Distance Run = (03h 56m) x 19.5 k = 76.7 **M**

True Course to steer **113.0**

d.Lat.	**dep.**	Mean latitude	**d.Long.**
30.0 S	70.6 E	41.0	93.5 E

DR_1 Position	Lat.	40 45.0 S	Long.	159 42.0 E
	d. Lat.	30.0 S	d. Long.	1 33.5 E
DR_2 Position	Lat.	41 15.0 S	Long.	161 15.5 E

2^{nd} Approximation

L.M.T.	1205 Aug. 12^{th}
± Long. w/ E (-)	1045
G.M.T.$_2$	0120 Aug. 12^{th}
G.M.T.$_1$	0126 Aug. 12^{th}
Interval	0006 (-)

Distance Run = (00h 06m) x 19.5 k = 2.0 **M**
True Course to steer (**113.0 + 180**) = **293.0**

d.Lat.	**dep.**	Mean latitude	**d.Long.**
00.8 N	1.8 W	41 14.6	2.4 W

DR$_2$ Position	Lat.	41 15.0 S	Long.	161 15.5 E
	d. Lat.	0.8 N	d. Long.	2.4 W
DR$_3$ Position	Lat.	41 14.2 S	Long.	161 13.1 E

Accurate GMT & Ch. Time of Noon sight

LHA	360 00.0	
± Long. w/ E (-)	161 13.1	
GHA	198 46.9	
Tab. GHA	193 43.1 →	01h
Incr.	5 03.8 →	20m 15s
GMT	01h 20m 15s Aug. 12^{th}	
Ch. Error (-)	1m 40s	
Ch. Time	01h 18m 35s	

Extract declination at G.M.T.$_2$

Dec.	15 06.2 N
d. Corr^n (-)	0.3
C. Dec.	15 05.9 N

To Find True Latitude:

Sext. mer. alt.	33 40.0 N
IE (-)	1.5
Obs. mer. alt.	33 38.5 N
Dip (-)	6.8
App. mer. alt.	33 31.7 N
Corr^n (+)	14.6
True mer. alt.	33 46.3 N
90 (~)	90
TMZD	56 13.7 S
C. Dec. (~)	15 05.9 N
True Latitude	41 07.8 S

Compass Error

Introduction

Compass readings, due to a number of internal and external causes, are subjected to systematic and random errors in magnitude, and to eliminate them from compass readings it is necessary to introduce a so-called total compass Error (C. E.)

When sailing in the open sea, the total compass error can only be found by taking bearings of celestial bodies. The magnitude and sign of C.E. are defined by the formula:

$$C.E. = T\ Bg._{body} - C\ Bg._{body}$$

Where: T $Bg._{body}$ is the true bearing of the celestial body.

C $Bg._{body}$ is the bearing of the body obtained by the compass.

Thus; the problem of determining the compass error is solved by taking the compass bearing of the body and computing its azimuth for that instant; the difference will be the compass error.
Obtaining compass error on steaming vessels is one of the most important missions of the watch officers. To check the corrections of the compasses is important through the watch when steady course and specially when altering courses.

Celestial bodies give a wide field to do this. Watch officer can obtain compass error by any of the following methods:

A. *General or Time Method*:
   Where the Compass Bearing of a body of low altitude (< 15°) above Eastern (or Western) horizon is taken and time is recorded.

B. Polaris Method (special case):
   Where the Compass Bearing of the pole star is taken and time is recorded.
   This method can be applied in north latitudes up to 35º N.

C. *Amplitude Method (when body is rising or setting)* :
   Where the Compass Bearing of the body (specially the sun) is taken at the moment of theoretical rising or setting.

Azimuth Circle

The Compass Bearing must be taken directly, without reflection on the azimuth circle`s mirror, to avoid errors of that mirror. To do that, altitude must be < 15°.

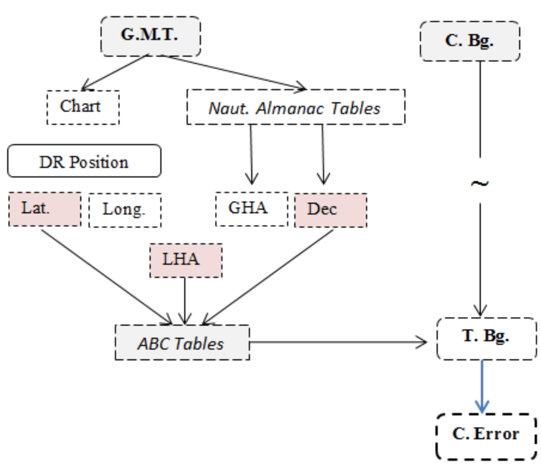
A- General (or Time) Method

Any celestial body of altitude less than 15º can be observed directly to obtain its compass bearing to avoid using the azimuth mirror. The azimuth mirror has many kinds of errors which can affect the compass error obtained; azimuth mirror can be used to reflect the image of the body observed in emergency conditions up to 35º altitudes. For altitudes more than 35º; the compass correction obtained is *unreliable.*

Practical Procedures to Apply the Method:

1) Get the compass bearing of the chosen body. (C. Bg.)
2) Record the time of bearing. UT (G.M.T.)
3) Extract the D.R. position from the chart. (DR Lat. & DR Long.)
4) Using UT (G.M.T); Extract L.H.A. & Dec. of the body from the *Nautical Almanac Tables*.
5) Apply A/B/C/ tables (or equations) to obtain True Bearing (T. Bg.).
6) Apply the formula C. E. = T. Bg. - C. Bg.; to obtain the compass error.

The previous steps are shown in the following flow chart:



Solved Example (1)

At Z.T. 2040 on September 13th ; 1990, ship was in D.R. position (29º 30`.0 N; 46º 40`.0 W). The following data were recorded:

- Ch. Error 5m 14s fast
- Variation (1978) 3º.0 E (decreasing 5` annually)

The star ***Arcturus*** was seen at low altitude on the western horizon.
It is required to check the error of the compasses .The star was observed as follows:

- Ch. Time 11h 45m 54s
- Compass Bearing 285º.0
- Gyro Bearing 286°.0

Calculate the error of each compass and the deviation.

Answer:

A. To find G.M.T.

Z.T.	2040 Sept. 13th
Z.N.	3 (+)
G.D.	2340 Sept. 13th

Ch. Time	11 45 54
Ch. Error	- 5 14
G.M.T.	23 40 40 Sept. 13th

B. *To find L.H.A. & Dec.*

G.H.A. γ	337 40.3
Incr.	10 11.7
SHA	146 11.5
G.H.A.*	134 03.5
±Long.	46 40.0
L.H.A.*	87 23.5

C. Dec 19 13.9 N

C. To Find True Bearing

L.H.A.	87 23.5	A	0.026 S
Lat.	29 30.0 N	B	0.349 N
Dec.	19 13.9 N	C	0.323 N
		Az.	N 74.3 W
		T. Bg.	285º.7

D. To find True Variation (1990):

$Var._{1990} = Var._{1978} - (5x12) = 3º.0\ E - 1º.0 = 2º.0\ E$

E. To find the errors & deviation

Compass		Gyro	
T. Bg.	285.7	T. Bg.	285.7
C. Bg.	285.0	G. Bg.	286.0
C. Error	0.7 E	G. Error	0.3 High
Var.	2.0 E		
Dev.	1.3 W		

Solved Example (2)

At Z.T. 1725 on Jan. 15th ; 1990, ship was in D.R. position (31º 15`.0 S; 125º 22`.0 W). The following data were recorded:

- Ch. Error 2m 56s fast
- Variation (1986) 1º.4 E (decreasing 6` annually)

Sun was seen at low altitude on the western horizon.
It is required to check the error of the compasses .Sun was observed as follows:

- Ch. Time 01h 27m 24s
- Compass Bearing 264º.0
- Gyro Bearing 260°.0

Calculate the error of each compass and the deviation.

Answer:

A. To find G.M.T.

Z.T.	1725 Jan. 15th
Z.N.	8 (+)
G.D.	0125 Jan. 16th

Ch. Time	01 27 24
Ch. Error	- 2 56
G.M.T.	01 24 28 Jan. 16th

B. To find L.H.A. & Dec.

G.H.A.	192 36.3
Incr.	06 07.0
G.H.A.	198 43.3
±Long.	125 22.0
L.H.A.	73 21.3

Dec.	21 01.2 S
d. Corr.	0.2
C. Dec	21 01.0 S

C. To Find True Bearing

L.H.A.	73 21.3
Lat.	31 15.0 S
Dec.	21 01.0 S

A	0.181 N
B	0.401 S
C	0.220 S
Az.	S 79.3 W
T. Bg.	259º.3

D. To find True Variation (1990):

Var. (1990) = 1º.4 E - 0º.4 = 1º.0 E

E. To find the errors & deviation

Compass

T. Bg.	259.3
C. Bg.	264.0
C. Error	4.7 W
Var.	1.0 E
Dev.	5.7 W

Gyro

T. Bg.	259.3
G. Bg.	260.0
G. Error	0.7 High

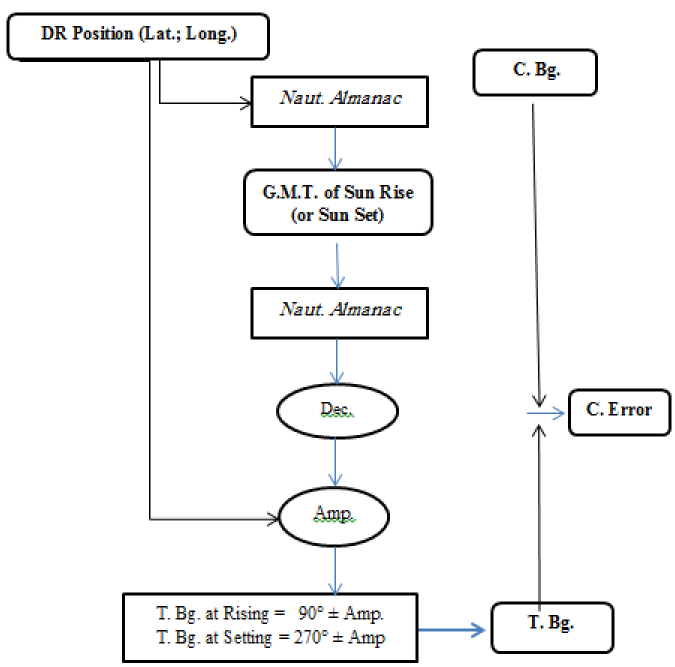
Amplitude Definition:

It the angle measured on the horizon circle, from East or West point to rising or setting point of the heavenly body respectively.

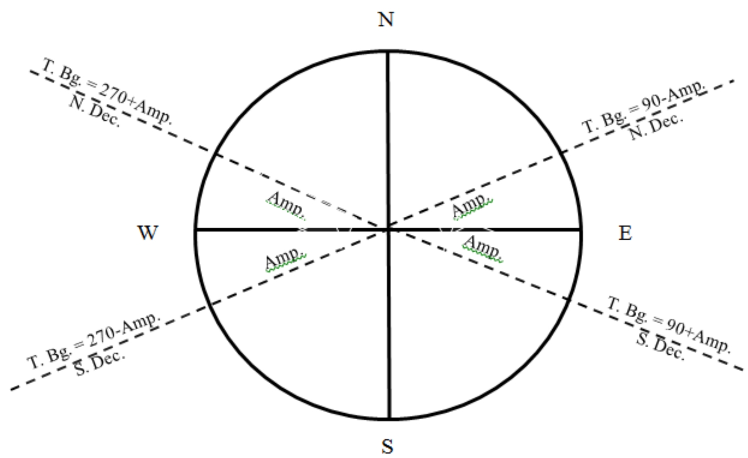
A. Proceed as follows to apply Amplitude method:

1. Get the compass bearing of the sun when theoretical rising (setting).(**C. Bg**.)
2. Calculate the time of theoretical rising (setting) (**G.M.T**.)
3. Using G.M.T.; Extract declination Dec. of the sun from *Nautical Almanac Tables*.
4. Extract the **D.R. Lat**. from the chart.
5. By the knowledge of Dec. of the sun & DR La.t.; calculate the Amplitude applying the formula sin Amp. = $\frac{\sin Dec}{\cos Lat.}$
6. Obtain the True Bearing (T. Bg.) by applying the suitable equation of * or ** or from diagram shown in next page.
   T. Bg. at Rising = 90° ± Amp. → (+ for South Dec. & - for North Dec.) *
   T. Bg. at Setting = 270° ± Amp. → (+ for North Dec. & - for South Dec.) **
7. Apply the formula C. Error = T. Bg. ~ C. Bg. To obtain the compass error.

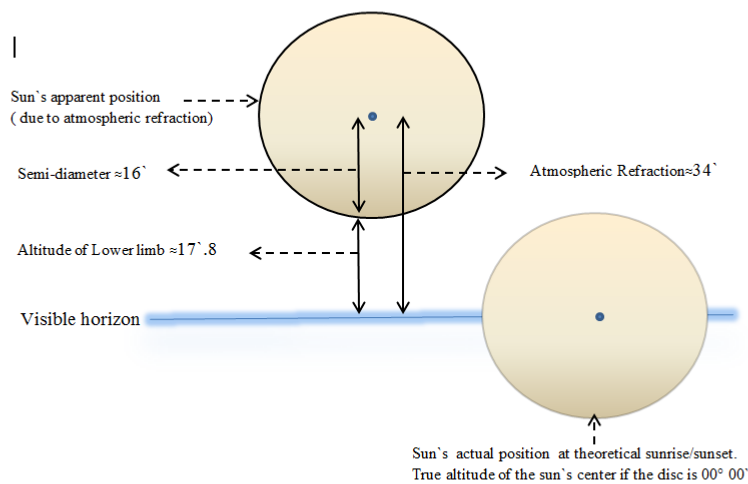
The previous steps are shown in the following flow chart:



B. Diagram of the relation between True Bearing and Amplitude



C. Condition to apply the formula of Amplitude



The Compass Bearing, in case of Amplitude method, must be taken when the lower limb of Sun`s disc is nearly equals the semi-diameter. This is the condition to apply the formula of Amplitude.

Solved Example (3)

On April 11th 1990, Ship was in D.R. position (42º 15`.0 S; 161º 20`.0 E)
Sun was observed at **theoretical rising** as follows:

- Compass Bearing 070º.0
- Gyro Bearing 080º.0
- Variation(1982) 3º.4 E (decreasing 3` annually)

Calculate the error of each compass and the deviation

Answer:

A. *To find G.M.T. of Sunrise*:

L.M.T.	0625 Apr 11th
Lat. corr. $^{\underline{n}}$	+ 2
L.M.T.	0627 Apr 11th
±Long	1045 (-)
G.M.T.	1942 Apr 10th

2 (TUES., WED., THURS.)				10
Lat.	Twilight Naut.	Twilight Civil	Sunrise	
°	h m	h m	h m	h m
N 72	////	02 35	04 04	22 35
N 70	////	03 02	04 17	21 51
68	01 36	03 23	04 28	21 23
66	02 13	03 39	04 37	21 01
64	02 38	03 51	04 44	20 45
62	02 58	04 02	04 51	20 31
60	03 13	04 11	04 56	20 19
N 58	03 26	04 19	05 01	20 09
56	03 37	04 26	05 06	20 00
54	03 46	04 32	05 09	19 53
52	03 54	04 38	05 13	19 46
50	04 02	04 43	05 16	19 39
45	04 16	04 53	05 23	19 26
N 40	04 28	05 01	05 29	19 15
35	04 37	05 08	05 34	19 06
30	04 45	05 14	05 38	18 58
20	04 57	05 23	05 46	18 44
N 10	05 06	05 31	05 52	18 32
0	05 13	05 37	05 58	18 21
S 10	05 18	05 42	06 04	18 09
20	05 22	05 47	06 10	17 58
30	05 25	05 52	06 16	17 44
35	05 25	05 55	06 20	17 36
40	[illegible]	[illegible]	06 25	17 27
45	[illegible]	[illegible]	06 30	17 17
S 50	05 26	06 03	06 36	17 05
52	05 25	06 04	06 38	16 59
54	05 25	06 06	06 41	16 53

B. *To find Dec.*

Dec.	8 03.7 N
d. Corr.	0.6
C. Dec	8 04.3 N

C. *To Find Amplitude:*

sin Amp. = sin Dec. / cos Lat.
sin Amp. = sin (8 04.3) / cos (42 15.0)
Amplitude = 10°.9

D. *To Find True Bearing:*

True Bearing = 90º ± Amplitude
T. Bg. = 90 - 10.9 = 079.1

E. *To Find Variation (1990):*

Var. $_{1990}$ = Var. $_{1982}$ – (3`x8) = 3°.4 E - 0°.4 = 3°.0 E

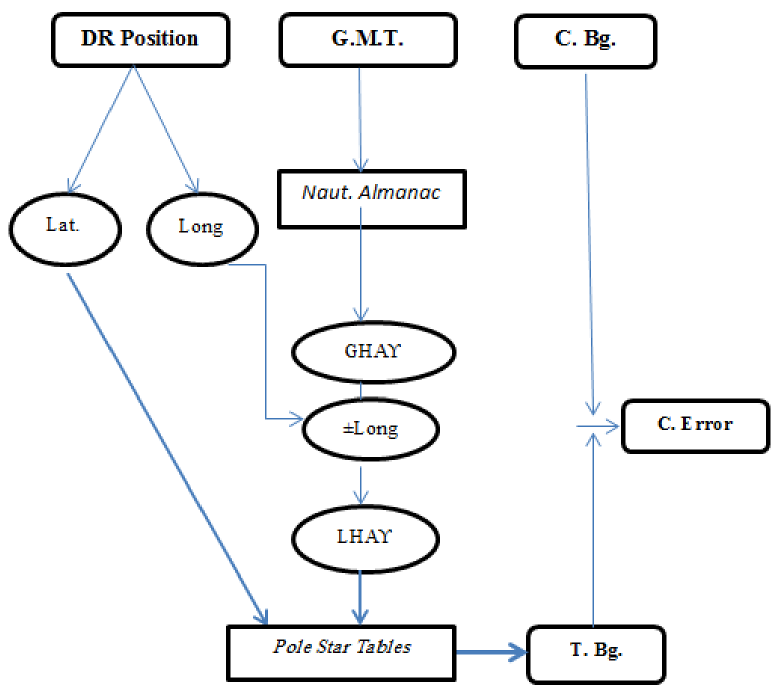
F. *To find errors & deviation*

Compass		Gyro	
T. Bg.	079.1	T. Bg.	079.1
C. g.	070.0	G. Bg.	080.0
C. Error	9.1 E	**G. Error**	0.9 High
Var.	3.0 E		
Dev.	6.1 E		

Proceed as follows to apply Polaris method:

1. Get the compass bearing of the Pole Star. (C**. Bg.**)
2. Record the time of compass bearing (**G.M.T**.)
3. Extract the **D.R. position** from the chart. (DR Lat. & DR Long.)
4. Using G.M.T.; Extract G.H.A. γ from *Nautical Almanac Tables*.
5. Add DR Long. To G.H.A. γ to obtain L.H.A. γ.
6. By the knowledge of L.H.A. γ & DR. Lat. Extract (T. Bg.) from Pole Star Tables (*In Nautical Almanac Tables)*.
7. Apply the formula C. Error = T. Bg. ~ C. Bg. To obtain the compass error.

The previous steps are shown in the following flow chart:



Solved Example (4)

During the morning twilight of November 13th, 1990,
Ship was in D.R. position (28º 04`.0 N; 170º 20`.0 E).
The pole star (***Polaris***) was seen very clear. It was a chance to check the errors of the compasses.
The following information was recorded:

- Ch. Time 6h 05m 40s
- Ch. Error 5m 12s slow
- Variation (1986) 2º.5 W (increasing 3` annually)
- Compass Bearing 003º.0
- Gyro Bearing 358º.0

Calculate the error of each compass and the deviation.
Answer:

A. To find correct G.M.T.

L.M.T.	0544 Nov 13th
Lat. Corr. n (+)	11
L.M.T.	0555 Nov 13th
± Long.(W/E) (-)	1121
G.D.	1834 Nov 12th

Ch. Time	06 05 40
Ch. Error	+ 5 12
G.M.T.	18 10 52 Nov 12th

POLARIS (POLE STAR) TABLES,
FOR DETERMINING LATITUDE FROM SEXTANT ALTITUDE

L.H.A. ARIES	120°–129°	130°–139°	140°–149°	150°–159°	160°–169°	170°–179°	180°–189°	190°–199°
	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0 54·8	1 02·9	1 10·9	1 18·5	1 25·4	1 31·6	1 36·8	1 40·9
1	55·6	03·7	11·6	19·2	26·1	32·2	37·3	41·2
2	56·4	04·5	12·4	19·9	26·8	32·8	37·7	41·5
3	57·2	05·3	13·2	20·6	27·4	33·3	38·2	41·8
4	58·0	06·1	14·0	21·3	28·0	33·8	38·6	42·1

July	0·7	0·7	0·8	0·8	0·9	0·9	1·0	1·0
Aug.	·5	·5	·6	·7	·7	·8	0·8	0·9
Sept.	·3	·4	·4	·5	·5	·6	·7	·7
Oct.	0·2	0·3	0·3	0·3	0·4	0·4	0·5	0·5
Nov.	·2	·2	·2	·2	·2	·2	·3	·3
Dec.	0·3	0·2	0·2	0·2	0·2	0·2	0·2	0·2

Lat.	AZIMUTH							
°	°	°	°	°	°	°	°	°
0	359·2	359·2	359·3	359·3	359·4	359·5	359·6	359·7
20	359·2	359·2	359·2	359·3	359·4	359·5	359·6	359·7
40	359·0	359·0	359·1	359·1	359·2	359·3	359·5	359·7
50	358·8	358·8	358·9	359·0	359·1	359·2	359·4	359·6
55	358·6	358·7	358·7	358·8	359·0	359·1	359·3	359·5
60	358·4	358·5	358·6	358·7	358·8	359·0	359·2	359·5

B. To extract L.H.A. γ

G.H.A. γ	321 36.3
Incr.	02 43.4
G.H.A. γ	324 19.7
± Long.(E/W) (+)	170 20.0
L.H.A. γ	**134 39.7**

C. To extract True Bearing:

Regarding POLARIS TABLES in (NAUTICAL ALMANAC)
→ T. Bg. = 359.1

D. To calculate variation 1990

Var. $_{1990}$ = Var. $_{1986}$ + (3`x4) = 2°.5 W + 0°.2 = 2°.7 W

E. To calculate errors & deviation

Compass		Gyro	
T. Bg.	359.1	T. Bg.	359.1
C. Bg.	363.0	G. Bg.	358.0
C. Error	3.9 W	G. Error	1.1 Low
Var.	2.7 W		
Dev.	1.2 W		