CHAPTER 17

Astronomy

17.1 Field Astronomy

- In Surveying, field astronomy is required where a high degree of precision is required by determining the absolute position of points on the earth. This is done in terms of **latitude** and **longitude.**
- The correct direction of the line is determined from the true bearing (or azimuth).

17.2 The Earth

- The earth is a sort of oblate-spheroid with smaller length of axis along the poles as compared to equator axis.
- It revolves about its polar axis from West to East with a time period of 24 hours.
- The ellipticity of the earth is expressed as

$$e = (\text{Equatorial radius} - \text{Polar radius})/2$$

- The ellipticity of the earth is about 0.52% ($H \approx 1/193$) and thus many times it is taken as sphere without incorporating appreciable error. The earth revolves around the Sun with a times period of $365\frac{1}{4}$ days.

17.3 Terminologies in Astronomy

- **Terrestrial Poles:** The polar axis of earth intersects at the earth surface at north and south ends and these points of intersection are respectively called as **geographical north** and **geographical south poles.** These two poles are collectively called as **terrestrial poles.**
- **Small circle and great circle:** The intersection of any plane with the earth's surface is called as **small circle.** When this plane passes through the equator then this is called as **great circle.** Thus equatorial plane is the great circle of earth.
- **Nautical mile:** It is the length of the arc of the great circle when it subtends an angle of 1 minute at the earth's centre. Thus,

$$1 \text{ Nautical mile} = \frac{2\pi R}{360 \times 60} = \frac{2\pi(6370)}{360 \times 60} = 1.853 \text{ km}$$

- **Celestial Sphere:** The whole universe is assumed to be a sphere of infinite radius with earth as its centre. The whole of the stars are considered to be embedded in this sphere.
- **Celestial poles:** The earth's axis of rotation when extended in both the directions meets the celestial sphere at **celestial north and celestial south poles.**
- **Celestial Equator:** The terrestrial equator when intersected by the celestial sphere gives rise to celestial equator.
- **Celestial horizon:** It is the great circle which is perpendicular to the zenith-nadir line and passes through the centre of the celestial sphere.
- **Celestial meridian:** It is the great circle passing through the celestial poles. In fact all meridians pass through the celestial poles.
- **Spherical trigonometry:** In spherical trigonometry, the curvature of earth is also taken into account. Here all measurements are done in terms of angles without any linear measurements. Thus distances are expressed as angle subtended at the centre of the sphere.
- **Spherical triangle:** Spherical triangle is the triangle formed by the intersection of three great circles. The angles formed at the three vertices of the spherical triangle are called as **spherical angles.** Spherical angle is formed by two great circles and is expressed as the angle between the tangents to the great circles at their point of intersection.

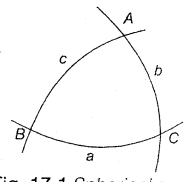

Fig. 17.1 *Spherical angle*

Salient characteristics of spherical triangle

1. The sum of lengths of any two sides of the spherical triangle is more than the third side.
2. The sum of three sides of the spherical triangle is always less than the circumference of the great circle.
3. If two angles of a spherical triangle are equal then opposite sides are also equal.
4. The sum of three angles of the spherical triangle is always greater than 180 degree and less than 540 degree.
5. Any angle of the spherical triangle is less than 180 degree.

- **Spherical Excess:** It is the amount by which the sum of three angles of the spherical triangle exceeds 180°.
- **Horizon:** It is the plane passing through an observer at right angle to the direction of gravity at the place of observation. It is also called as **Sensible Horizon.**
- **Zenith and nadir:** Zenith is the point directly above the observer's head i.e. point where the vertical line through the head of the observer intersects the celestial sphere. The corresponding point directly below the observer in the opposite hemisphere is called as nadir.
- **Declination circle of a celestial body :** The declination circle of a celestial body is the celestial meridian which passes through the celestial body.

  Alternatively, declination (δ) of a celestial body is the angular distance measured on star's meridian north or south of the celestial equator. It varies from 0° to 90°.

  Plus (+) When place is on north of equator

  Minus (–) When place is south of equator

- **Hour angle:** The hour angle of a celestial body is the angle between the observer's meridian and the meridian of the declination circle of the celestial body. It is measured towards west from 0° to 360° or from 0 to 24 hour (by taking 15° = 1 hour).
- **Vertical circle :** These are the great circles through zenith and nadir.
- **Prime vertical:** A vertical circle which is at right angles to the meridian.
- **East and west points:** These are the points on which prime vertical meets the horizon.
- **Altitude (α):** The altitude of a celestial body is its angular distance above the horizon measured on vertical circle passing through the body.
- **Co-altitude / zenith distance:** It is the complement of altitude i.e. (90° – α). It is the angular distance between the body and the zenith. **(Fig. 17.3)**
- **Azimuth:** The azimuth of a celestial body is the angle between the observer's meridian and the vertical circle through the celestial body. It is measured on the horizon from 0° to 360° from north towards east.
- **Latitude (θ):** The latitude of a place is the angle between the plumb line at that place and the equator.

  Plus (+) When place is on north of equator

  Minus (–) When place is south of equator
- **Colatitude:** It is complement of latitude i.e. (90° - θ).
- **Longitude:** It is the angle between the fixed meridian (i.e. prime meridian) and the meridian of the place of the observer. The normally adopted prime meridian is the Greenwich. It is measured on the plane of equator and is expressed in degrees or hour, minutes and seconds.
- **Right ascension (RA):** RA of a celestial body is the angle between declination circle through the first point of aries and declination

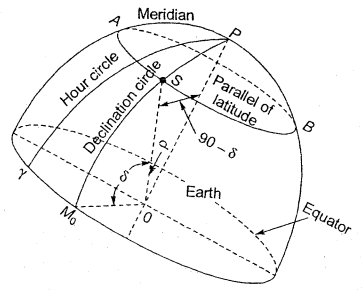

Fig. 17.2 *Hour Circle*

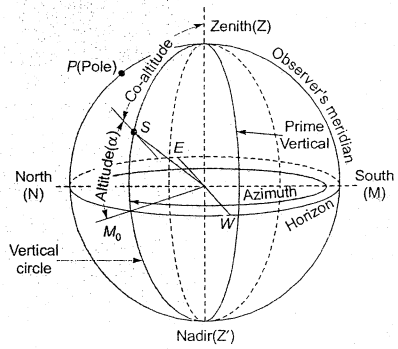

Fig. 17.3 *Celestial horizon*

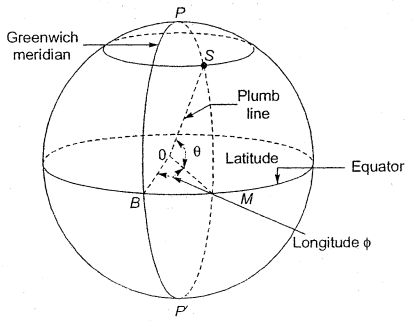

Fig. 17.4 *Longitude of a place*

circle of the body (i.e. hour circle). It is measured towards east and varies from 0° to 360°.

17.4 The Sun

- The sun is located at a distance from 149.6 x 10^6 km from the earth.
- The diameter of the sun is about 109 times that of the earth.
- The sun's diameter subtends an angle of 31′59″ at the earth's center.
- Sun's surface temperature is about 6090 °C and about 12 million °C at its center.
- The Sun is assumed to rotate about its own axis but is considered at rest with respect to the Earth.
- The sun has two apparent motions viz. one w.r.t. earth and other w.r.t. the stars. The former one results from the real motion of earth and that toc in the plane of earth's orbit. This plane passes through the center of celestial sphere and intersects the celestial sphere in a great circle called as **ecliptic**.
- The ecliptic plane is inclined to the equator i.e. obliquity of ecliptic is 23°27′.
- Thus the earth's axis of rotation is inclined at 66°33′ (= 90° – 23°27′).

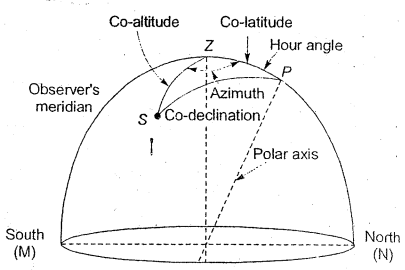

Fig. 17.5 *Spherical triangle*

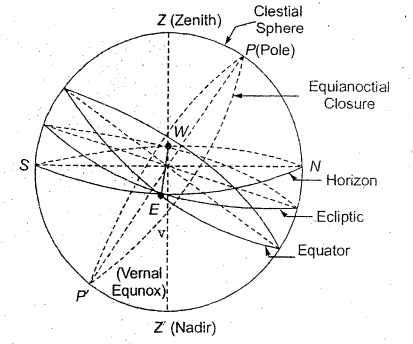

Fig. 17.6 *The celestial sphere*

- **Vernal equinox:** The earth's axis is perpendicular to the line joining earth and sun on 21st March. The sun comes in the equatorial plane and passes the equatorial plane from south to north. This is also called as first point of aries. Days and nights are of equal duration throughout the earth.

  Note : Equinox means equal nights.
- **Summer solstice:** On 21st June, the earth's axis is in a plane perpendicular to the ecliptic. The sun is vertically above the tropic of cancer at 23.5°N.

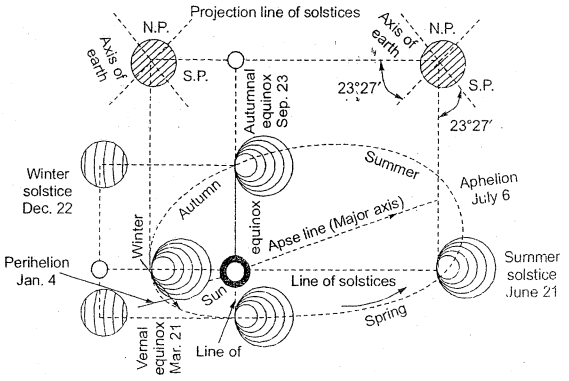

Fig. 17.7 *Effects of earth's annual motion*

- **Autumnal equinox:** On 23rd September, the sun again passes through the equatorial plane from north to south. It is also called as point of first libra. The days and nights are of equal duration throughout the earth.
- **Winter solstice:** On 22nd December, the sun is over the tropic of capricorn at 23.5°S.

17.5 Locating the Position of Celestial Body

- Any points on the earth's surface can be located completely by it corresponding latitude and longitude.
- Similarly the position of a body on the celestial sphere can be located.

17.5.1 Co-ordinate Systems for Locating a Celestial Body

(a) Altitude-azimuth System

- The reference plane is horizon.
- It is assumed that at the instant of observation, all celestial bodies are at rest.
- The altitude and azimuth depend on the position of the observer.
- This system is suitable for permanently recording the position of celestial bodies.

(b) Right Ascension and Declination System

- Equator is taken as the reference plane
- Right ascension, spherical co-ordinates and declination are required to locate a body on the celestial sphere.
- Slow secular movement of equatorial plane due to disturbing couple of attraction forces from the sun, moon and planets on earth's surface is called as Precession.
- Variation in the valve of precession couple is called nutation.
- Precession and nutation make changes in the right ascension and declination of a celestial body.

(c) Declination and Hour Angle System

- Equator is taken as the reference plane.
- Oberver's meridian is the reference direction.
- Point of intersection of celestial equator and meridian is called as reference point.

17.6 Solution of Spherical Triangle

Sine formula $$\frac{\sin a}{\sin A} = \frac{\sin b}{\sin B} = \frac{\sin c}{\sin C}$$

Cosine Formula $$\cos a = \cos b.\cos c + \sin b.\sin c.\cos A$$

$$\cos A = -\cos B\cos C + \sin B\sin C\cos a$$

If $$s = \frac{a+b+c}{2} \text{ and } S = \frac{A+B+C}{2}$$

then $$\sin\left(\frac{A}{2}\right) = \sqrt{\frac{\sin(s-b)\sin(s-c)}{\sin b.\sin c}}$$

$$\cos\left(\frac{A}{2}\right) = \sqrt{\frac{\sin s.\sin(s-a)}{\sin b.\sin c}}$$

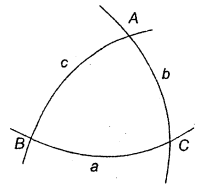

Fig. 17.8 *Spherical Triangle*

$$\tan\left(\frac{A}{2}\right) = \sqrt{\frac{\sin(s-b)\sin(s-c)}{\sin s.\sin(s-a)}}$$

$$\tan\left(\frac{a+b}{2}\right) = \frac{\cos\left(\frac{A-B}{2}\right)}{\cos\left(\frac{A+B}{2}\right)}.\tan\left(\frac{c}{2}\right)$$

$$\tan\left(\frac{a-b}{2}\right) = \frac{\sin\left(\frac{A-B}{2}\right)}{\sin\left(\frac{A+B}{2}\right)}.\tan\left(\frac{c}{2}\right)$$

$$\sin\left(\frac{a}{2}\right) = \sqrt{\frac{-\cos S.\cos(S-A)}{\sin B\sin C}}$$

$$\cos\left(\frac{a}{2}\right) = \sqrt{\frac{\cos(S-B)\cos(S-C)}{\sin B\sin C}}$$

$$\tan\left(\frac{a}{2}\right) = \sqrt{\frac{-\cos S.\cos(S-A)}{\sin(S-B)\cos(S-C)}}$$

$$\tan\left(\frac{A+B}{2}\right) = \frac{\cos\left(\frac{a-b}{2}\right)}{\cos\left(\frac{a+b}{2}\right)}.\cot\left(\frac{C}{2}\right)$$

$$\tan\left(\frac{A-B}{2}\right) = \frac{\sin\left(\frac{a-b}{2}\right)}{\sin\left(\frac{a+b}{2}\right)}.\cot\left(\frac{C}{2}\right)$$

17.7 Time

- The earth rotates about its axis and also around the Sun.
- This introduces TIME element in astronomical work.
- The earth revolves in an spherical path with sun as one of its foci. This gives rise to variable speed of earth.
- Sun's apparent variable motion is used for measuring the time.

17.7.1 Time Terminologies

(a) Sidereal time :

- Measurement of time is based on diurnal motion of star.
- Parallax, nutation, observation, precession, refraction etc. affects the apparent position of star.

(b) Sidereal day :

- Time interval between to successive upper transits of first point of arise over the same meridian.
- It is divided into 24 hours with 60 minutes per hour and 60 seconds per minute.

(c) Sidereal year :

- Time required by the sun to make one complete round of ellipse with reference to star on the ellipse.

(d) Apparent Solar Time (AST) : It is the westerly hour angle of the sun's centre.

(e) Solar Day :

- Time interval between to successive lower transit of sun's center over the meridian of the place.
- Lower transit being chosen so that date change occurs at midnight.

(f) Mean Solar Time (MST) :

- Sun moves relative to the celestial sphere which is not uniform.
- Thus a mean sun assumed which is regarded as a point travelling the celestial equator at a uniform rate to make solar days of uniform span.
- Motion of mean sun is average of true sun is its right ascension. It differs from the actual sun by upto $\frac{1}{4}$ hour.

(g) Greenwich Mean Time (GMT) :

- Measured from hour transit of Greenwich meridian by mean sun.
- It is also called as universal time.

(h) Equation of time (ET) :

- Non-uniform motion of Sun along the ellipse gives rise to different values of near and apparent solar times.
- At any instant, it is the difference of apparent and mean, solar times.
- The values ET at zero hour at Greenwich are given in nautical almanac. It varies from 0 to 6 minutes in different seasons of the year.
- +ET → Apparent time + ET = Mean time
  − ET → Apparent time − ET = Mean time

(i) Standard Time :

- Different local times create confusion and may cause havoc.
- A particular meridian is selected called as standard meridian. Which is applicable for the whole country.
- This standard meridian is so selected that it lies at an exact number of hours from Greenwich.
- Time referred to standard meridian is called as standard time.
- In India, the standard meridian is 82°30′E passing through Allahabad.

Standard time = LMT ± difference of longitude of place W/E

Plus (+) → when place is west of meridian

Minus (−) → when place is east of meridian

Greenwich time = Local ± longitude of place W/E

Plus (+) → when place is west of Greenwich

Minus (−) → when place is east of Greenwich

Illustrative Examples

Example 17.1 Find the Local Mean Time (LMT) of a place having a longitude of 95°45′ E when standard mean time is 10 hr 05 min 17 sec. The standard meridian is at 76°30′E.

Solution:

Given longitude of place = 95°45′E

Longitude of standard meridian = 76°30′E

$\therefore$ Difference in longitude = 19°15′E = 1 hr 5 min 00 sec.

Now given place is towards east of standard meridian.

$\therefore$ standard time = LMT – difference in longitude

$\Rightarrow$ LMT = 10 hr 05 min 17 sec + 1 hr 5 min 00 sec

$\Rightarrow$ LMT = 11 hr 10 min 17 sec

Example 17.2 The LMT at a place with longitude 64°35′E is 07 hr 21 min 16 sec. The said place is situated in India. Find the standard time.

Solution:

standard meridian for India is 82°30′E = Longitude of standard meridian

Longitude of place = 64° 35′E

$\therefore$ Difference in longitude = 82° 30′ – 64° 35′ = 17 °55′ = 1 hr 11 min 2.67 sec

The place is towards west of standard meridian

$\therefore$ Standard Time = LMT + difference in longitude

= 07 hr 21 min 16 sec + 1 hr 11 min 2.67 sec

= 08 hr 32 min 18.67 sec

Example 17.3 Find the LMT at a place with longitude of 64°30′E if GMT is

(i) 6 hr 20 min 3 sec a.m. on 7th may

(ii) 6 hr 20 min 3 sec p.m. on 7th may

Solution:

Longitude of place = 64° 30′E = 4 hrs 18 min

The place is located east of Greenwich

(a) GMT = LMT – longitude of place

$\Rightarrow$ 6 hr 20 min 30 = LMT – 4 hr 18 min

$\Rightarrow$ LMT = 10 hr 38 min 3 sec a.m. on 7th may

(b) GMT = 6 hr 20 min 3 sec p.m.

= 18 hr 20 min 3 sec past midnight

GMT = LMT – longitude of place

$\Rightarrow$ 18 hr 20 min 3 sec = LMT – 4 hr 18 min

$\Rightarrow$ LMT = 22 hr 38 mm 3 sec = 10 hr 38 min 3 sec pm.

Example 17.4 The clock time at a given instant on 25th may 2015 is 10:30 p.m. at a particular Indian city *A*.

Spherical co-ordinates of city *A* : 30° 25′27″N, 80° 55′E

Indian standard longitude for time : 82° 30′E

Find LMT and GMT corresponding to local time.

Solution:

Difference between longitude of city A and Indian standard longitude

= 82° 30′ – 80° 55′

= 01° 35′ = 0 hr 6 min 20 sec

City A is towards west of Indian standard longitude.

IST = LMT + Difference of longitude

$\Rightarrow$ LMT = 10 hr 30 min – 0 hr 6 min 20 sec

= 10 hr 23 min 40 sec p.m. on 25th may 2015

Difference of longitude between IST and GMT

= 82° 30′ – 00° 00′ = 82° 30′ = 5 hr 30 min

Indian standard longitude is towards east of Greenwich meridian.

$\therefore$ GMT = LMT – Difference of longitude of IST and GMT

= 10 hr 23 min 40 sec – 5 hr 30 min = 4 hr 53 mm 40 sec

= 4 ! 53 ! 40 p.m. on 25th may 2015

Objective Brain Teasers

1. One nautical mile is equal to:
   (a) 1853 m (b) 1760.5 m
   (c) 565.8 m (d) 1005.5 m

2. The Sun appears to trace the great celestial sphere with Earth at its center during the year. This is called as:
   (a) Prime vertical (b) Ecliptic
   (c) hour angle (d) None of these

3. One minute arc of longitude is called as:
   (a) one mile (b) one sextant
   (c) one light year (d) one nautical mile

4. The International Meridian passes through:
   (a) Stockholm (b) Allahabad
   (c) Greenwich (d) Copenhagen

5. The line of Indian Standard Time passes through
   (a) Kanpur (b) Bhopal
   (c) Nagpur (d) Allahabad

6. The difference in longitudes of two places when expressed in terms of time is equal to difference in their:
   (a) Mean solar time
   (b) Sidereal time
   (c) apparent solar time
   (d) All of these

7. The angle between the observer's meridian and declination circle of the heavenly body is referred to as:
   (a) Declination (b) Hour angle
   (c) Sidereal time (d) Azimuth

8. The reference plane in the altitude and azimuth system of co-ordinates is:
   (a) Horizon (b) Prime vertical
   (c) Equator (d) None of these

9. 1° latitude is equivalent to a distance of:
   (a) 105 km (b) 405 km
   (c) 111 km (d) 587 km

10. If S denotes the sum of all the angles of a spherical triangle then the quantity S-180? is called as:
    (a) Spherical deficiency
    (b) Spherical excess
    (c) Spherical misclosure
    (d) All of these

11. The solar system consists of _____ of known planets.
    (a) 12 (b) 11
    (c) 10 (d) 9

12. The inclination of ecliptic with the equator is:
    (a) 36° 45′ (b) 27° 55′
    (c) 23° 27′ (d) 72° 27′

13. When the Earth in its orbit is nearest to the Sun, then it is called as:
    (a) Perihelion (b) Apogee
    (c) Aphelion (d) Perigee

ANSWERS

1.	(a)	2. (b)	3. (d)	4. (c)	5. (d)
6.	(d)	7. (b)	8. (a)	9. (c)	10. (b)
11.	(d)	12. (c)	13. (a)		