Chapter-5

MOTION OF THE EARTH

Looking from distant sky the earth is seen as a mass of land,sea and air. Depending on the movement within Earth and the energy from the sun, each of these is changeable. The Earth is continually spinning in space. It is not only circling the sun,it is spinning on its own axis as well. The length of the day, the length of the year and the season depends on the orientation of the Earth's axis and the motions of the Earth. The earth spins around the axis, which passes through the north and the south geographic poles. But the axis is not a vertical line. It is tilted so that the Earth orbits the sun at a certain angle [See figure 5.1]. A year is the time the Earth takes to make one complete circuit around the sun. A day is the time the Earth takes to make one complete turn on its axis. The spin of Earth on its axis is gradually slowing down. 400 million years ago a year was about 400 days long. This was because the Earth was spinning faster and produced shorter day.

Systems of celestial coordinates are used to describe the positions of the celestials bodies. There are four different systems of celestial coordinates

1.Horizon system

2.Equatorial system.

3.Ecliptic system

4.Galactic system

In horizon system, the latitude is referred to the projection of the observer's horizon on the celestial sphere and the longitude is the azimuth. The angle is measured from 0^0 to 360^0 starting from the northern direction in the clock wise direction. In equatorial system, the celestial latitude denoted by δ-is measured in degree of arc north(+) or south(-) of the celestial equator. The celestial longitude α is measured in degree or hours eastward. In ecliptic system the celestical longitude and

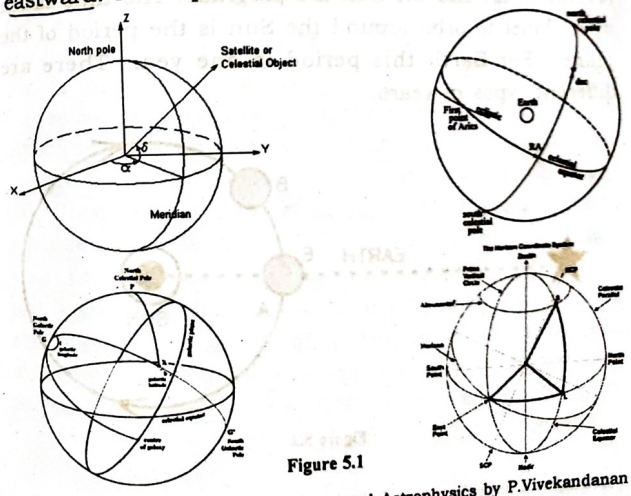

Figure 5.1

the celestial latitude are the two co-ordinates. In Galactical system the galactical latitude is referred to the galactical equator and galactical longitude is measured eastward, starting from the direction of the galactical centre. The four coordinate systems are shown in figure 5.1.

The angular velocity of Earth about its spin axis is 7.27×10^{-5} rad/s. The Earth revolves around the sun at a speed of 29.78 km/s. The sun moves towards the star Vega at a speed of 19.5 km/s with respect to the neighboring stars, at the same time together with the neighboring stars move around the galactic centre at a speed of 225 km/s.The net motion of the sun with respect to the background radiation is 380 km/s towards the constellation Leo.

The rotation of the Earth about its axis and its revolution around the Sun are prograde. The time taken by a planet to orbit around the Sun is the period of the planet. For Earth this period is one year. There are different types of years.

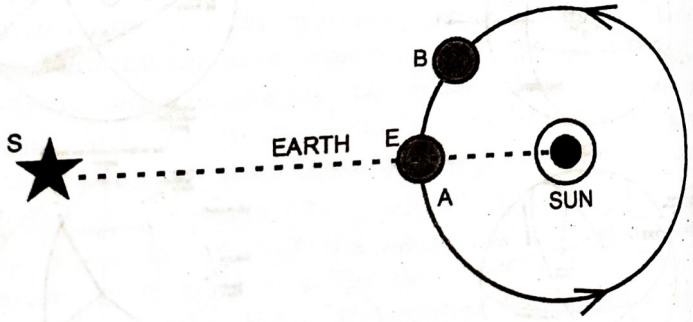

Figure 5.2

S is a distant star and E is the Earth, The direction of revolution of Earth is shown by the arrow mark [Figure 5.2]. Starting from A the time taken by the Earth to make one complete revolution and return to the point A is called one sidereal year and is equal to 365.2563656 days . For example suppose the summer solstice in the Northern Hemisphere (June 21) occurs at the point A. But the next solstice will not be at A, it will be at another point say B, due to the precession of Earth's axis. The time taken by the Earth to move from A to B is called the tropical year which is equal to 365.24219342 days. This year is the year for the human being including scientist. The tropical year is shorter than the sidereal year due to the precession of the Earth. The shape of the Earth is not a perfect sphere. It bulges slightly in the middle. When Earth spins, the place on the equator move much faster than places near the poles. The faster the rotation, the stronger will be the centrifugal force. The materials are pushed out from the centre of rotation. Thus the equator bulges out due to spinning motion. The equatorial radius is greater. Hipparchus discovered,that there is a precessional motion of the Earth's axis in the clockwise direction as seen from the North. This arises from the change in the torque applied by the moon, the Sun and the Planets especially on the bulging part. Earth precesses in the anti-clockwise direction at an angle 0.12" per year due to the torques applied by the planets. The lunisolar precession is 50.40" per year . Thus the net precession is 50.28" in the clockwise direction. Suppose there was no precession. Then Earth would have returned to the point A after one year. Due to precession the tropical year is shorter by 20 minutes 25s than the sidereal year.

THE CALENDAR

The name calendar is derived from the Latin name for the day of the new moon, which marks the begining of lunar month. Early civilizations used the movements of object in the sky as a calendar, as means of navigation or to predict events in their lives. The basis of calendar is the subdivison of time into years, months, weeks and days. All these divisons are based on phenomena having different period. The revolution of Earth around the sun, the revolution of the moon about the Sun, the revolution of moon about the Earth and the rotation of the Earth. In a lunar month there are 29.53 days, 4.22 weeks and 365.24 days in a tropical year.

Flooding fertilized the delta. So Egyptians started their year in latter past of July, becuase it was then the Nile began flooding the delta. According to Egyptians one year had 12 months of 30 days each. Then total 360 days and they added 5 days at the end. Egyptian calendar was developed in 4241 BCE (Before the Common Era). It was in use for 3000 BCE.

Egyptian calendar was adopted by Greeks. Their year had 365.25 days. The begining of the year was fixed at either summer or winter depending the Greek city. During 753 BCE, Romans had a calendar of 10 months out of which 4 months had 31 days and six had 30 days. The names of month were Martius, Aprilis, Maius, Junius, Quintilis, Sexilis, September, October, November and December. The last two months were unnamed in the begining, later the two months were named as Januarius and Februarius. The year then started from 1st January. To make the year to have 365.25 days one

day was added to February every fourth year. Later the names Quintilis and Sextiles were changed to July and August. The first Julian year began on January 1,709 AUC, (Ab Urbe Condita means since the founding of city). Instead of starting a calendar from the date of founding of Rome, Dionysins Exiguusa made it from the birth of Jesus Christ on the of Byzantine Emperor Justinian in 526 CE. The number of days in a tropical year fixed by Julius Ceaser was not exact. Pope Gregory XII corrected it, thus came Gregorian calendar, which was made by Christopher Clavius and the Neapolitan astronomer and physician Luigi Lilio Ghiraldi. This new calendar, was adopted by all the European countries and then by England. After a few years Russia also accepted. Before accepting this calendar their year had 13 days less and English people's calender was 12 days behind. In the same year 1582 Joseph Scaliger deviced Julian period named after his father Julius Ceaser Scaliger. The Julian period was used to record the dates of various celestial phenomenon. The Julian period is obtained by multiplying three cycles, the Solar (28Y), Metonic (19Y) and Indictio (15Y) i.e. $28 \times 15 \times 15 = 7,980$ years. The solar cycle is a period of 28 years, the Metonic cycle is a period of 19 years and the Indicito cycle is a period of 15 years.

By definition there are 60 minutes in one hour and 60 seconds in a minute. So the number of seconds in one day is 86,400. The solar day is longer than sidereal day. The sidereal day is the time taken for a distant star to return to the same celestial meridian. It is the time taken by the earth to make one full turn and is equal to 23 h, 56 m, 4.1 s. The solar day is the time taken for the sun

to return to facing the same terrestrial meridian and is equal to 24 hrs. Since the solar day is greater it is necessary for the Earth to turn an additional 59' 8.2" in order for the sun to return to the same meridian. The time required for this additional turning is 3m 56.5s. According to Kepler's second law the planets do not move along their orbits with constant speed. Thus the speed of Earth is maximum at prihelion and minimum at aphelion. But its angular velocity remains constant, so the length is greater at perihilion than at aphelion. Mean solar day is the time interval between successive passage of the mean Sun at meridian. The second is defined as 1/86,400 of mean solar day and is called ephemeris second. In

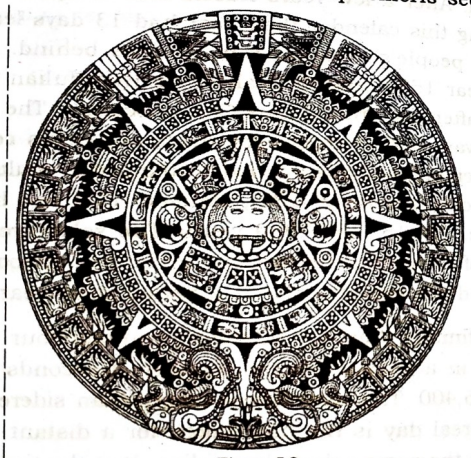

Figure 5.3

1967 the ephemeris second was replaced by atomic second. It is the duration of 9,192,631,770 cycles of radiation corresponding to the transition between the

the two hyperfine levels of ground state of $^{133}C_s$. The mean solar time counted from midnight at the greenwich meridian is called the Geenwich Mean Time (GMT). It is also called Universal Time (UT) or Zulu (Z) time. The Greenwich Mean Time counted from noon at the Greenwich Meridian is called Greenwich Mean Astronomical Time (GMAT). The Mayan's calender is as shown in Figure 5.3. According this calender the end of the world is on 21.12.2012.

The day is divided into 24 hours. The meridian directly facing sun is at noon and the opposite meridian is at midnight. The Earth's surface was divided into zones 15° of longitude wide and each zone correspond to one hour. In 360° there are 24 zones and hence 24 hours so that $15^0 \times 24 = 360^0$. The time zones are marked A to M eastward and N to Y westward, starting with time zone Z bisected by the Greenwhich meridian.

The word week is derived from the Latin word septmana for seven or a Greek word which means seven. There were seven known planets and each planet was related to a day, Sun for Sunday, Moon for Monday, Mars for Tuesday, Mercury for Wednesday, Jupiter for Thursday, Venus for Friday and Saturn for Saturday.

THE SEASON

The Earth leans at an angle of 23°26'28" from the normal to the orbital plane and spins around an imaginary line joining the North and South poles. One hemisphere gets more Sunlight than the other and therefore more heat. The change in temperature through the year causes the seasons. When the northern hemisph ere is tilted towards the Sun there is summer and if

tilted away from the sun there is winter. When northern hemisphere has summer, then there will be winter in

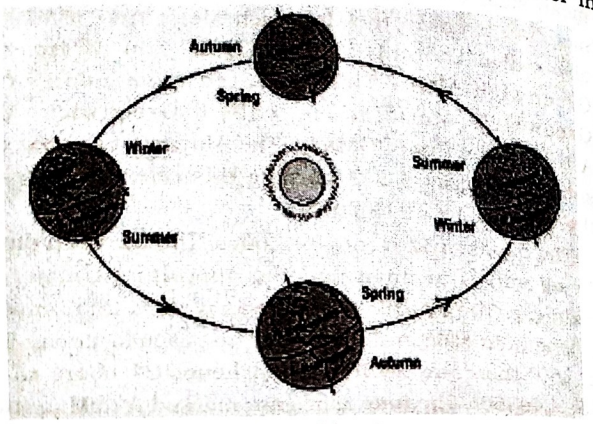

Figure 5.4

southern hemisphere and vice versa [See Figure 5.4]. Places at the equator always get the full heat of the sun. The poles has only two seasons, six month of summer and six month of winter. Places between the poles and tropics have four seasons. They gradually change from spring to summer then to autumn and finally to winter. Christmas in December, it is winter in countries like Norway and Canada, and they have snow. But in Southern hemisphere, Australia, it is summer. During the Northern Summer the Sun's rays are perpendicular to the tropic of cancer the southern polar cap recieves no sunlight but the Northern polar cap recieves maximum. During the equinoxes, Mar 21, September 23 the sun's rays are perpendicular to the equator and the both hemisphere recieves the same amount of heat. Yearly temperature

extremes are felt about one month after the solstice becuase of the thermal inertia of the hydro atmosphere. The Seasons move along the orbital plane due to the general precession. The processional angle changes with time and correspondingly the inclination of Earth's axis to the normal to the orbital plane also change. This has a periodicity of 40,600 years. The eccentricity of the Earth's orbit changes from a minimum value of 0.01 to a maximum of 0.07 with a certain periodicity. When eccentricity is high the seasonality or hot summers and cold winters, will be extreme. When eccentricity is minimum, the seasonality is also minimum. Due to the combined effects of precession of Earth's axis and changes in orbital eccentricity periods of cool summers occur every 100,000 years. Thus the astronomical motions of the Earth set the pace of the ice ages.

MODEL QUESTIONS

BUNCH I

SECTION A

OBJECTIVE QUESTIONS

1. 400 million years ago a year of Earth was about
   a) 300 days b) 365 days
   c) 400 days d) 100 days
2. There are ____ different systems of celestial co-ordinates
   a) 2 b) 3
   c) 4 d) 5
3. The angular velocity of Earth about its spin axis is
   a) 7.27×10^{-5} rad/sec b) 360 rad/sec
   c) 180 rad/sec d) 90 rad/sec
4. The Sun moves towards the star Vega at a speed of
   a) 195 km/sec b) 10km/hr
   c) 20km/hr d) 100km/sec
5. The tropical year is ____ sidereal year
   a) Shorter than b) longer than
   c) same as d) non of the above
6. Who discovered that there is a precessional motion of the Earth's axis in the clockwise direction as seen from the north.
   a) C. V Raman b) Bose
   c) Hipparchos d) Aryabhatta
7. In a lunar month there are ____ days
   a) 30 b) 29
   c) 29.53 d) 31
8. During 753 BC, Romans had a calendar of ____ months only
   a) 6 b) 8

   c) 10 d) 12
9. The mean ____ time counted from mid night at the Greenwich meridian is called GMT
   a) Day b) solar
   c) lunar d) week
10. During the northern summer the sun rays are ____ to the Tropic of cancer.
    a) Perpendicular b) parallel
    c) inclined d) none of the above

BUNCH II

FILL IN THE BLANKS

1. When ____ is minimum the seasonality will also be minimum.
2. A _____ is the time the Earth takes to make one complete circuit around the Sun.
3. Systems of ____ coordinates are used to describe the positions of the celestial bodies.
4. In galactic system the galactic latitude is referred to the ____ equator.
5. The equator of the Earth bulges out due to the ____ motion.
6. When Earth spins, the places on the equator move much ____ than places near the pole.
7. Due to ____ the tropical year in shorter than the sidereal year.
8. Egyptians stared their year in the latter part of ____.
9. The ____ period was used to record the dates of various celestial phenomenon.
10. The ____ cycle is a period of 15 years.

BUNCH III

TRUE OR FALSE

1. The solar cycle is a period of 28 years.
2. In 1900 the ephemeris second was replaced by atomic second.
3. One hemisphere of the Earth gets more sunlight than the other.
4. The poles have only two seasons.
5. During equinoxes, March 21, September 23, the Sun rays are perpendicular to the equator.
6. The precessional angle of Earth changes with time.
7. The eccentricity of the Earth's orbit changes from a minimum value of 0.05 to a maximum value of 0.07.
8. In horizon system, the longitude is referred to the projection of the observer's horizon.
9. The sidereal year and tropical year are the same.
10. When Earth spin the places on the pole move faster than the places near the equator.

SECTION B

VERY SHORT ANSWER QUESTIONS

1. Name the different motions of the Earth?
2. On what factors do the length of the day and the length of the year depend?
3. What are celestial coordinates?
4. Name the different types of celestial coordinates?
5. What is the angular velocity of Earth about its spin axis?
6. What do you know about the motion of the Sun?
7. What is sidereal year?
8. What is tropical year?
9. How is calendar prepared?

10. How did Egyptians prepare calendar?
11. How was the beginning of the year found by the Greeks?
12. Where did Julian year begin?
13. What is sidereal day?
14. Does Earth move with the same velocity in its orbit?
15. What is ephemeris second?
16. What is GMT?
17. How many zones are there in 360⁰?
18. How did Sunday and Monday get their names?

SECTION C

LONG ANSWER QUESTIONS

1. Explain how the motion of the Earth is related to the length of the year. Explain the difference between sidereal year and the tropical year. How does Earth's precession affect length of the tropical year?
2. Discuss the history behind the formation of calendar and explain how it was developed in various countries.
3. How does various seasons occur? Explain how it is related to the Earth's precession

ANSWERS

OBJECTIVE QUESTIONS

1.c	2.c	3.a	4.a	5.a
6.c	7.c	8.c	9.a	10.a

FILL IN THE BLANKS

1. Eccentricity	2. Year
3.celestial	4. Galactic
5. spinning	6. Faster
7. precession	8. July
9. Julian	10. Indiction

TRUE OR FALSE

TRUE → 1,3,4,5,6

FALSE → 2, 7, 8, 9, 10