36A

SUN AND THE SOLAR FAMILY

36.1 INTRODUCTION

We live in an immense Universe. The Earth is of great importance to us, but in the Universe as a whole it is utterly insignificant. So, too, is our Sun without which life on our Earth would cease to exist. We have day when we are in the part of earth illuminated by the Sun. During the night we see the Moon, stars and a few star-like objects which change positions relative to the background of "fixed starts". All objects in the sky appear to move across the sky from east to west. This apparent motion arises because of the rotation of the Earth on its axis from west to east. It takes nearly 24 hours for our Earth to complete one rotation on its axis.

We also know that the Earth revolves around the Sun and it takes one full year to complete one revolution. It is moving in a nearly circular path of radius about 15 crore kilometre (1.5×10^{11}m). But our Earth is not alone in its journey around the Sun. In fact, a large number of objects such as *planets along with their satellites, asteroids, comets revolve round the Sun.* These are members of the Sun's family or the *Solar System.* The motion of all the members of solar system is governed mainly by the gravitational force of the Sun. In this lesson we will learn in brief about the various components of the solar system and some of their characteristics.

36.2 OBJECTIVES

After studying this lesson, you should be able to :

- *state important physical properties of the Sun;*
- *describe some interesting* phenomena *on the Sun such as* sunspots, *prominences and flares and explain the* sun-spot *cycle;*
- *describe the structure of the Sun and name the components of solar atmosphere and state their characteristics;*
- *name the nine planets of the Sun in order of their increasing distances from the Sun;*

- *differentiate between : (i) inferior planets and superior planets; (ii) inner planets and outer planets; (iii) terrestrial planets and the Jovian planets (gas giants) and (iv) meteoroids, meteors and meteorites;*
- *describe the characteristics of asteroids;*
- *describe the evolution of planets of the solar system.*

36.3 THE SUN

We know that the Sun is the head of the *Solar Family*. But it is just a medium star. It appears so bright because of its relative proximity to our Earth. In comparison to Sun, **distance of the nearest star, Proxima Centauri,** is close to 3 lac times.

The Sun is a huge ball of gas with a surface temperature of about 5800 K and still higher inside. At this temperature no piece of matter can stay solid or even liquid. In comparison to it, the temperature of coal fire is only about 2000 K and that of filament of an electric lamp is only 3000 K. It radiates not only visible light but in the entire electromagnetic spectrum, much like the radiation of the hot filament of an electric lamp.

The mass of Sun is 2×10^{30} kg, which is about one third of a million times that of the Earth and more than a thousand times that of the largest planet Jupiter. You may be surprised to know that *the Sun contains roughly 99.9% of the mass of the entire solar system* and, therefore, is practically at rest – everything else revolves around it, bound by its gravitational attraction. But the picture gets completely reversed if we compute the angular momentum possessed by the Sun and by planets. Sun has about 0.5% of the angular momentum of the entire Solar System.

We all know that the coal has stored solar energy. It was absorbed by the plants long ago and was converted into chemical energy, which is now released by combustion. Petroleum too, owes its energy content to the Sun. As a matter of fact all energy that we use on the Earth, except possibly the nuclear energy, comes from the Sun.

36.3.1 Observing Solar Surface

The Sun is so near to us that we can study its surface in much greater detail than any other star, even with small instruments. Since the Sun is blindingly brilliant, you will have to take special precautions while observing it. You are advised *never to look at the Sun directly, except during 2 or 3 minutes immediately after sun-rise or immediately before sun-set.* Staring at the Sun with the naked eye, even for a short duration, can cause damage to the eyes. The *safest technique of observing the Sun is to project its image onto a white surface by a* telescope. We can also observe it by placing a special Sun-filter on the telescope, provided the filter is of dependable quality and correct density. A sun filter of good quality reduces brilliance of sun to safe lavel and cuts off ultra-violet light. with in a few minutes after sun rise or before sun set atmosphere also does the same to the brilliant sun.

INTEXT QUESTIONS 36.1

1. *Why is the sun practically at rest while the planets revolve around it?*

   ....

2. *What is the safest method for observing the solar surface at any time of the day?*

   ....

3. *How a good* sun-filter *makes observation of sun safe?*

   ....

36.4 THE STRUCTURE OF THE SUN

What is the sun made of? What is the temperature, pressure and density in various portions of it? How does it give so much energy? Let us study these and similar questions.

36.4.1 General Features

If you make spectrum of the light coming from the Sun, you notice that it is a continuous band crossed by many absorption lines. Light from a hot object (e.g. filament of an electric lamp) contains all wavelengths. When this light passes through a cooler layer, atoms in the cooler layer absorb their characteristic wavelengths. The spectrum of light which **passes through** it is crossed by dark lines for these wavelengths. Hence, it is called an ***absorption spectrum***. Similar arrangement exists in the Sun (and all stars). We shall consider it in more details in Lesson 38.

90% of Sun's mass is contained within half of its radius, i.e.1/8th of its volume. Its average density is 1410 kg/m^3 (for comparison, the density of water is 1000 kg/m^3). But, the pressure and density at the centre is very high due to gravitational pull on every portion of Sun directed towards the centre. It has been estimated that the pressure reaches about 3×10^{11} atmosphere and that temperature reaches about 15×10^6 K. Due to high pressure, the density at the centre of the Sun is around 150000 kg/m^3. In contrast, the density in outer layers of photosphere is very small, of the order of 10^{-5} kg/m^3.

Under these conditions, nuclei of atoms are stripped of their electrons and they are quite close to each other. Due to their high thermal energies, electrostatic repulsion between positively charged nuclei is overcome. Thus, they can come into contact and *nuclear reactions* can take place and produce energy. We shall study more about these reactions in Lesson 38.

36.4.2 The Photosphere

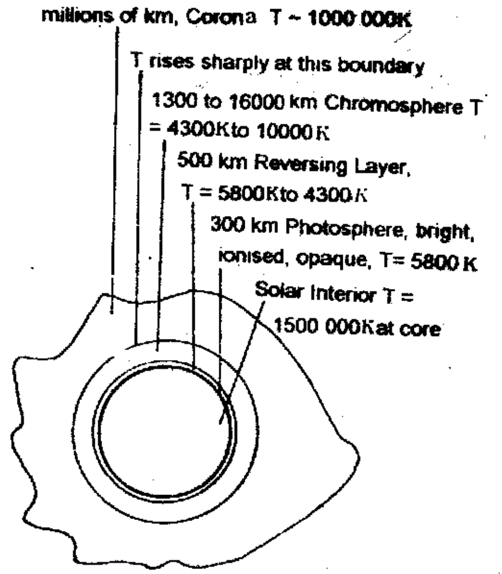

Fig. 36.1: The solar surface & atmosphere

While discussing the tempera -ture of the Sun, we refer to the Sun's surface which is actually a misnomer. *What we call the surface of the Sun is a thin layer of hot (temperature about 5800 K) and highly ionised gases* which continuously receives energy from interior of the Sun and gives it out in the form of heat, light and other radiations.

It is called the *photosphere.* (Fig. 36.1).

Above the photosphere, temperature continues to fall for some distance (about 500 km) and reaches down to about 4300 K (Fig. 36.1). This layer is responsible for absorption lines in the solar spectrum. It is called the *reversing layer.*

36.4.3 The Solar Atmosphere

The entire gaseous layer beyond the photosphere upwards, which is accessible to direct observation, forms the *solar atmosphere* (Fig. 36.1). It consists of two parts.

1. The layer next to photosphere is called *chromosphere.* It extends to about 13000 km to 16000 km above the photosphere. Its lower layers form the reversing layer in which temperature decreases outwards upto about 4300 K. In the main chromosphere, temperature gradually rises to about 10000 K. In a thin layer at its outer boundary temperature abruptly rises to a few million kelvin.
2. The outer most layer of the Sun's atmosphere is called *corona* (or crown). Its temperature is a few million kelvin. There is neither sharp division between the chromosphere and the corona, nor is the outer limit of the corona clearly defined. The corona may extend as far as our Earth and some astronomers are of the opinion that it may reach even farther.

The *chromosphere and corona are both very faint due to their very low density.* Due to this very reason they are extremely transparent too. Thus they can only be seen during total solar eclipse when the disc of Moon hides the bright photosphere. At any other time the glare of millions of times brighter photosphere masks them. During total solar eclipse again through the solar atmosphere you can also see distant stars quite close to the solar disc, with the help of a good telescope.

During total solar eclipse corona is visible with the naked eye as a silvery cloud around the dark Moon covering the Sun. As the Moon moves across the solar disc, there comes a moment *when bright photosphere is completely covered, but the chromosphere is not yet covered.* Then the chromosphere is seen for a few seconds as a reddish-pink crescent (Fig. 36.2). Soon the Moon covers the chromosphere also. The chromosphere is so called due to its colourful appearance only. This colour is produced by the emission of light from the abundent atoms (hydrogen) in this layer.

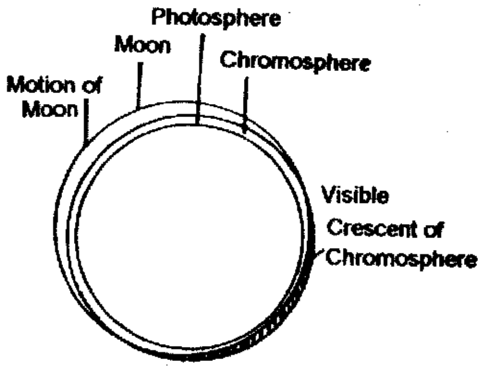

***Fig. 36.2:** Situation when chromosphere is visible*

If we observe the *spectrum of chromosphere when it is seen as a crescent during total solar eclipse, it is an emission spectrum* having bright lines emitted by atoms of elements in it. We call it *flash spectrum* because it is seen for a short time. The element helium was first identified in the Sun by the flash spectrum and only thereafter, it was found to exist on the Earth also.

Temperatures higher than that of photosphere in the chromosphere and corona do not imply that they should be emitting more intense electromagnetic radiations than photosphere. Atoms in these regions are so far apart that there are few collisions among them. Only few atoms ionise or excite to higher energy states. Thus only very feeble radiation is emitted by these regions. Brightness of these regions rapidly decreases outwards, as density also rapidly decreases, although temperature increases. The high temperature only implies that atoms and molecules of gases in these regions are moving at high velocities.

INTEXT QUESTIONS 36.2

1. *Describe briefly, what exactly it is, that appears to us as surface of the Sun.*

   ....

2. *What is flash spectrum? When is it observed? Why is it observed for a very short duration?*

   ....

3. *When can we observe corona? Why can we not see it along with photosphere of Sun at any time of the day?*

   ....

36.5 THE SOLAR SYSTEM

You have studied earlier that our solar system consists of a star – the Sun – around which orbit nine major planets. Which are these planets in order of increasing distance from the Sun? You have studied that these are :

1. Mercury (Budha)
2. Venus (Shukra)
3. Earth (Prithvi)
4. Mars (Mangal)
5. Jupiter (Vrihaspati)
6. Saturn (Shani)
7. Uranus
8. Neptune
9. Pluto

In figure 36.3 the relative sizes of these planets and the Sun are shown. Planets are very tiny compared to the Sun. The largest planet (Jupiter) is 1/10th, Earth about 1/100th and the smaller (Pluto) about 1/600th of Sun in diameter. Except Mercury and Venus which have no satellite, numerous satellites revolve around these planets. Sixty satellites are actually known now, but it is probable that there exist others not yet discovered, specially around the most distant planets. In addition to major planets and their satellites, there are a great many minor planets called ***asteroids,*** countless ***comets*** and smaller pieces of orbiting rocks called ***meteoroids*** in the solar system.

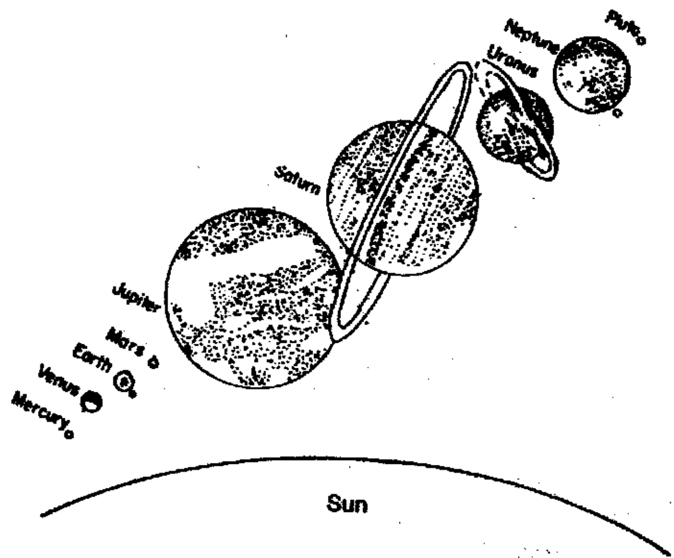

Fig. 36.3: *Relative sizes of planets and the sun.*

36.5.1 General Features of Solar System

It is remarkable that most of the planets move in nearly circular orbits. To be exact, they move in elliptical orbits with Sun always at one of the focii of these orbits. Eccentricity, a measure of deviation of an ellipse from circular shape, is generally small for these orbits. What we call distance of the planet from the Sun is, then, the mean distance of the planet. Thus we say "distance of Earth from Sun is 1.496×10^{11} m", though it can be upto 1.6% greater or smaller than this value. *The mean distance of Earth from Sun is taken as a unit for expressing distances within the solar system. It is called Astronomical Unit (A.U.).*

All these planetary orbits are almost in the same plane. The plane of Earth's orbit is called the ***Plane of the Ecliptic.*** Inclinations of the planes of other orbits are within 7° from this plane, except the orbit of Pluto.

Starting *from Sun. the first four planets are called* ***inner planets*** *and the rest five are called* ***outer planets.*** The four inner planets, viz. Mercury, Venus, Earth and Mars, are relatively small, *rocky bodies and thus are also known as* ***terrestrial planets.*** Jupiter, Saturn, Uranus and Neptune are known as the ***gas giants*** *because of their gaseous composition and relatively large size.* These are also called ***Jovian Planets,*** after the planet Jupiter, which was the first one whose gaseous nature was recognised. Pluto, wandering at the edge of the solar system is, in many ways, unlike any of the other planets.

Mercury and Venus are also known as the ***inferior planets,*** *because their orbits come inside the orbit of the Earth.* On the other hand, the six planets from Mars onwards are known as the ***superior planets,*** *since their orbits are outside the orbit of the Earth.*

All the planets revolve about the Sun in the same sense, anticlockwise if we look at them from the north side of the solar system. When the rotation of a planet is also in this direction, the rotation is said to be ***direct.*** In the opposite case the rotation is termed as ***retrograde.*** Among the planets, Venus, Uranus and Pluto have retrograde rotations (table1 at the end of the book).

36.5.2 Elongation of a Planet

Referring to Fig.36.4 (a) when a planet approaches closest to Sun as seen from Earth (position P_1) during its orbital motion, the planet is said to be in ***conjunction*** with the Sun. At that time it may actually be a little to north or to south of the Sun. But due to glare of the Sun, it can not be seen.

This configuration soon changes, because angular velocity of an inferior planet around Sun is more than that of Earth. Thus after

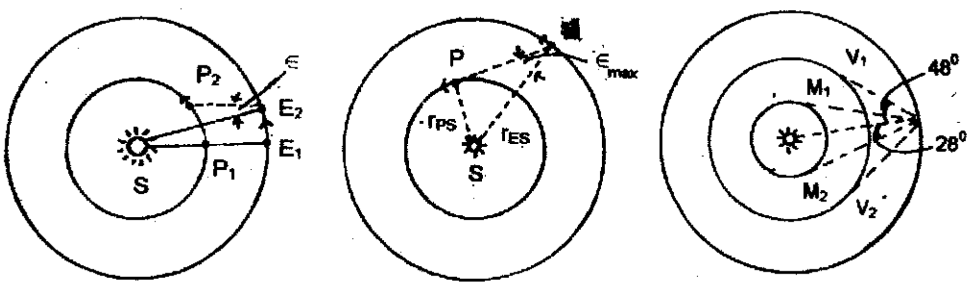

Fig.36.4 *: a, b, & C*

sometime when Earth reaches position E_2, the planet reaches position P_2, then the angle $P_2 E_2 S$ (symbol ϵ), i.e. *the angle between the directions of Sun and the planet as seen from Earth* is called its ***elongation.*** The planet is then seen to the west of Sun and *rises before the Sun in the morning.* Thus it is said to be visible as a ***morning star.***

The value of ϵ to west of Sun goes on increasing till observer's line of sight to the planet is tangential to orbit of the planet Fig. 36.4 (b). Then its value starts decreasing and becomes zero when the planet is again in conjunction with the Sun and behind the Sun. Thereafter the planet is seen to east of Sun, and is *visible in the evening after the sun set.* In that configuration the planet is termed as an ***evening star.*** Eastern elongation of the planet also goes on increasing, reaches the same maximum value (if orbits are circles) and then starts decreasing.

In this manner, the elongation of Venus varies from about 48° west to 48° East. Similarly, the elongation of Mercury varies from about 28° West to 28° East during its motion around the Sun (Fig.36.4c).

When the elongation of an inferior planet is maximum, it is seen as exactly half with the help of a telescope. This is so because at maximum elongation EP is tangent to orbit of P, i.e. angle EPS is a right angle. If this elongation is ϵ_{max}, you can easily prove that :

$$\boxed{r_{PS} = r_{ES} \sin \epsilon_{max}} \quad \text{.......................} \ (36.1)$$

$$\Rightarrow r_{PS} = \sin \epsilon_{max} \text{ A.U. (since } r_{ES} = 1 \text{ A.U.)}$$

We can find ϵ_{max} by regularly observing the planet. Thus, the distance of the planet from Sun can be found.

36.5.3 Kepler's Third Law of Planetary Motion

Activity: Calculate the ratio r^3/T^2 for different planets, where T is the sidereal period of revolution and r is the mean distance of the planet from Sun. Does this ratio change from one planet to another? For actual data of solar system see the table 1 at the end of this book.

You will find that the ratio r^3/T^2 is constant for all planets. This is ***Kepler's III law of planetary motion.*** Kepler discovered it from the data of measurements made by Tycho Brahe. Later on, Sir Issac Newton could derive it from his law of gravitation.

If M and m are masses of Sun and a planet, G is the constant of gravitation, then the force of attraction between them (Fig. 36.5) is

$$F = \frac{GMm}{r^2} \quad \text{......} \ (36.3)$$

This provides the centripetal force for uniform circular motion of the planet, which is mv^2/r . Therefore :

$$\frac{GMm}{r^2} = \frac{mv^2}{r} = \frac{m}{r} \times \left(\frac{2\pi r}{T}\right)^2$$

$$\text{or, } \frac{GM}{4\pi^2} = \frac{r^3}{T^2} \quad \text{.........} \ (36.3)$$

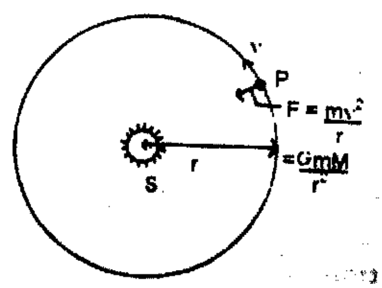

Fig.36.5: *Gravitational pull of sun provides centrepetal force to keep the planet revolving in the orbit*

It would be clear from eq.36.3 that if a number of satellites revolve around any celestial object, $GM/4\pi^2$ is the same for those satellites, M being the mass of that celestial object. Hence, r^3/T^2 is constant for those satellites, which is Kepler's III law. Thus it is true for all planets revolving around Sun, or for moons of Jupiter, or for a number of artificial satellites launched by Man to revolve around Earth, etc. It would further be clear that if we know r and T for any of the satellites, M the mass of that celestial object can be calculated.

INTEXT QUESTIONS 36.3

1. *Name the various categories of objects which constitute the Solar system.*

   ....

2. *What is meant by (a) inner planets and outer planets and (b) inferior planets and superior planet? (c) terrestrial planets and (d) gas giants?*

   ....

3. *Earth makes one revolution around Sun in 365.25 days in a nearly circular orbit of radius 1.5×10^{11} m. Find the mass of Sun. (Value of constant of gravitation is $G = 6.7 \times 10^{-11}$ Nm^2 kg^{-2})*

   ....

4. *Venus makes one revolution around Sun in 224.70 days and Earth* in 365.26 days. How much time will Venus take to make one revolution *more than Earth, i.e. after a conjunction with the Sun it will make the next conjunction with the Sun.*

   ....

5. *Maximum elongation of Venus is observed to be 48°. Find the radius of its orbit in AU and in km.*

   ....

36.6 MAGNETIC FIELDS IN THE SOLAR SYSTEM

Whereas gravitation controls the motion of planets and all other bodies around the Sun, there are many phenomena in the Solar system, which are due to the magnetic fields present in the Sun and other members of Solar System.

36.6.1 Magnetic Field of Earth

You are all familiar with the compass needle. It keeps a fixed direction, because the Earth behaves like a huge bar magnet. Thus it has a magnetic axis, which is a line in the direction of its magnetic moment and passing through its centre. It is inclined at

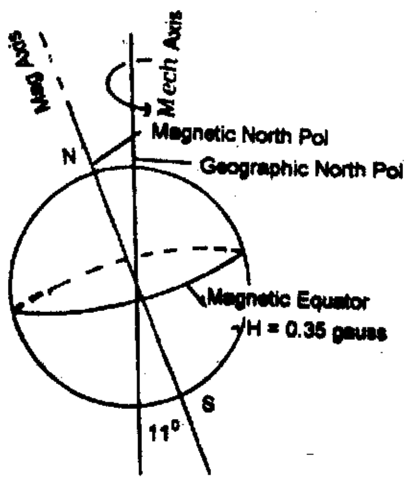

Fig. 36.6 : *Magnetic axis of earth is at 11° to axis of its mechanical rotation*

about 11° to its axis of mechanical rotation (Fig.36.6). *Points where the magnetic axis meets the surface of Earth are magnetic poles of Earth. An imaginary circle on the surface of Earth equidistant from magnetic poles is magnetic equator of Earth.* At the magnetic equator, magnetic field is horizontal and of intensity 0.35 gauss's or 0.35×10^{-4} tesla. At other places it is inclined to horizontal, and has different intensities.

How does the Earth get its magnetic fields? Deep inside the Earth, the temperature is so high that the metallic substances present there are in a molten state. These molten metals are electrically conducting. As this conducting material rotates due to Earth's rotation, it generates a circular current. As you may have studied earlier in Lesson 18 on electricity and magnetism, the electric current generates a magnetic field. It is this magnetic field, that we observe on the surface of Earth with the help of the compass needle. The magnetic field of the earth is also due to other factors such as charged ions circulating around it.

36.6.2 Magnetic Field of Sun

Now, let us consider the case of our Sun. At its surface (photosphere) and inside, temperature is so high that mutual collisions of atoms knock out their electrons. Thus the gases are highly ionised. The entire gaseous Sun is, thus, a good conductor of electricity. The Sun also rotates with a period of about 25 days at the equator. Its period of rotation gradually increases at higher latitudes and becomes about 35 days near its poles. Then what do you expect about magnetic field of sun?

Like in the Earth, movements of conducting gases in the Sun generate a magnetic field which spreads over the whole Sun. It has a magnetic north pole and a magnetic south pole too, like that of Earth. Magnetic axis of Sun is tilted at about 15° to its axis of mechanical rotation.

36.6.4 Sun-spots and granulation

Sunspots are *temporary dark spots on the Sun's surface* (Photosphere). The central portion of a sunspot is called ***umbra*** (Fig. 36.7). It is darker and its temperature is between 4000 K and 4500 K. It is surrounded by ***penumbra*** where temperature may be only about 100 K to 300 K lower than surrounding photosphere. Outside diameter of penumbra is around 2 to 3 times the diameter of umbra. The Shape of both may, of course, be much different from circular.

The temperature inside sunspots are much higher than that of the filament of an electric lamp (3300 K). The so called 'dark spots' must then be very bright indeed. Why at all do they appear dark? They are cooler and thus less bright than surrounding photosphere.

In umbra of a sunspot, measurements show that there is a strong magnetic field, which is of the order of 10^4 times that on Earth's surface, i.e. a fraction of a tesla. Sunspots usually appear in groups of two or more. In a group of two, one spot is a north pole and the other is a south pole. Thus, it is like a huge magnet. In a large group of many spots, south and north poles are jumbled up.

Fig. 36.7 *: Sun-spots and granulation*

A typical sunspot is roughly as big as Earth. The smallest ones may be 1/10th to 1/20th of Earth in linear dimensions. The largest ones may be bigger than 10 Earths. Individual sunspots may last anywhere between a few hours to a few months. The longest living ones have been observed to last as long as 1.5 years.

There is a regularity in the number of sunspots on the solar disc. There are times when no sunspots are seen and other times when there are many. The number of spots is minimum roughly after every 11 years. In fact this period varies between 9 and 12.5 years. This phenomenon is called **sunspot cycle.** Sunspots almost always occur in the latitude range 5° to 40° on each side of the solar equator.

You can also observe in the fig. 36.7 that photosphere has a mottled appearance. It is not uniformly bright. It has a large number of small bright areas called **granules**. Adjacent granules are separated by a slighter darker region. A typical granule is of the order of 1000 km in size.

INTEXT QUESTIONS 36.4

1. *What is a sunspot? why does it appear dark. though its temperature is above 4000 K?*

   ....

2. *The year 1705 and also 1968 were the years of sunspot maximum (i.e. average number of sunspots on the surface of sun was*

maximum). How many more sunspot maxima have occurred between these years? Take period of sunspot cycle as 11 years.

....

3. What is meant by Earth's magnetic axis, magnetic poles, and magnetic equator? How is the Earth's magnetic field generated?

....

36.6.4 Solar Flares

A **solar flare** is a *sudden, tremendous, explosive outburst of electromagnetic waves and charged particles from the Sun.* During its short duration, a large solar flare may release as much energy as a billion large size hydrogen bombs would release. It may also hurl up billions of tons of material into space. A typical flare may last for about 10 minutes to an hour.

They occur near sunspots and seem to be energised by strong local magnetic fields. They are more frequent when there are many sunspots on the solar disc. Flares are seen as bright spots on the solar disc in a photograph taken by using a single wave length ($H\alpha$ line).

The electromagnetic waves of all wave lengths produced by a flare reach the Earth in about 8 minutes. The charged particles reach in a day or two, in the form of a burst of solar wind. These could cause considerable harm to life on Earth, if it were not shielded by its magnetic field and atmosphere. Gamma-rays, X-rays and short ultra-violet rays are absorbed by the atmosphere. They merely cause some ionisation in the atmosphere.

You already know that a force on a charged particle having charge q as it enters a magnetic field B with its velocity v being in a plane perpendicular to lines of force is qvB perpendicular to both v and **B**. This force compels it to move in a circle in the plane perpendicular to lines of force. Thus it cannot penetrate deep into the magnetic field. If the particle has a component of velocity along the lines of force too, then it spirals along the lines of force.

Thus, when a charged particle from a solar flare enters the Earth's magnetic field, it spirals along the lines of force and enters the Earth's atmosphere near its magnetic poles (Fig.36.8). Thus most of the areas on the Earth are protected from these particles. The high energy particles which enter the atmosphere near magnetic poles ionise the air, producing light. These lights near north pole

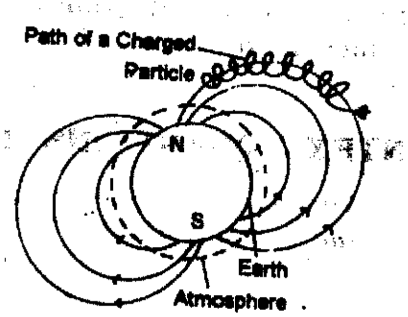

Fig. 36.8

are called **aurora borealis** and those near the south pole are called **aurora australis**. Auroras are visible a day or two after a solar flare.

You can also abserve in the fig 36.7 that photosphere has a mottled appearence. It is not uniformly bright. It has a large number of small bright areas called granules. Adjecnt granules are seperatid ly a slighter darher region. A typical granule is of the order of 1000 km in size.

INTEXT QUESTIONS 36.5

1. *What is a solar flare?*

   ....

2. *What are granules on the surface of Sun?*

   ....

3. *What is a prominence? How does the total solar eclipse help to observe it?*

   ....

36.7 OTHER MEMBERS OF THE SOLAR SYSTEM

In addition to the nine planets and their satellites, there are three other types of objects which belong to our solar system. These are asteroids, meteoroids and comets. Let us know in brief about them one by one.

36.7.1 Asteroids (The Minor Planets)

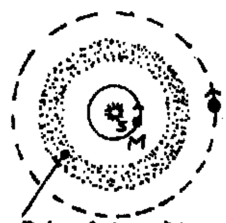

Fig. 36.9: Belt of astoroids between orbits of Mars and Jupiter

On 1st January 1801 an Italian astronomer found a small moving object between Mars and Jupiter, which he called Ceres. Since that time nearly 2800 similar moving objects have been discovered and it is estimated that there are perhaps 100,000 more having diameters larger than 1 km. Majority of these lie in a belt between the orbits of Mars and Jupiter (Fig.36.9). They are called ***asteroids*** because they look like stars and at the same time they are really minor planets or **planetoids. They** all revolve around the Sun in the same direction as the larger planets.

Cerrs has a diameter nearly 1000 km and the other asteroids are smaller, some being a kilometer or slightly more. Only one asteroid named **Vesta** is ever visible with the naked eye.

Scientists have discovered that the asteroids are found throughout the inner solar system. More than fifty asteroids are now known to cross the Earth's orbit. Thus, in theory atleast, it is possible that sometime in future one of these may come close enough to Earth, get attracted to Earth and fall down as a large meteor, causing havoc. It is thought that when dinosaurs suddenly disappeared 65 million years ago, it was due to an asteroid impact, although evidence in favour of this theory is far from conclusive.

36.7.2 Comets

Comets are tiny members of the Solar System revolving round the Sun, generally in a very elongated orbit (Fig.36.10), probably originating from a cloud of such objects far away from the Sun. Though sometimes they become very spectacular and large in size on coming close to Sun, but by planetary standards, their masses are very low indeed.

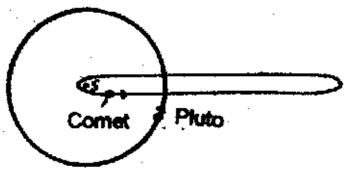

Fig. 36.10 : Highly elongated elliptical orbit of a comet

Comets are celestial objects composed of *ice*, i.e. frozen water, ammonia and methane. Mixed with the ices are some metallic dust particles also. They move round the Sun in highly elliptical or parabolic orbits and most of the time they keep themselves away from the Sun.

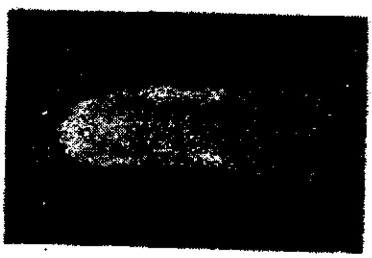

Fig. 36.11 : Nucleus, head and tail of a comet

When far away from the Sun, a comet is not visible as it has initially a small size of a few kilometers in diameter, and a low illuminance. As a Comet approaches the inner Solar System, the ice sublimate and some of the dust grains are released. This creates an atmosphere of gas and dust particles that we observe as the comet's fuzzy ***head*** or ***coma*** of the order of 10,000 km diameter, around the ***nucleus*** whose size is only a few kilometers (fig. 36.11). The comets also develop a ***tail*** as the comet passes close to Sun on its orbit. It always keeps pointing away from the Sun (Fig.36.12).

Fig. 36.12: Comet develops a tail as it passes close to the sun in its orbit

There are some comets which show their appearance after fixed regular intervals of time. These are called ***periodic comets.*** Halley's Comet is a periodic comet. Dr. Edmund Halley in 1682 observed this comet and computed its period of revolution to be approximately 76 years. This is the only periodic comet that can become a bright naked-eye object. Halley's comet made its appearance in 1910 and in 1986. Since its period of revolution is approximately 76 years, it is expected to return in 2062.

The number of known comets is increasing all the time as new ones are discovered. You can also discover a new comet, if you have a good telescope with objective mirror of 25 cm or bigger.

36.7.3 Meteoroids

There are many tiny particles usually smaller than a grain of sand, but sometimes tens of metres in diameter, orbiting the Sun. When beyond the Earth's atmosphere these particles are much too small and faint to the seen and are collectively known as ***meteoroids.*** When attracted by the Earth's gravity, they enter the upper reaches of the atmosphere, become heated by friction and thus destroy themselves in streaks of radiance, popularly known as ***shooting stars*** or ***falling stars*** or ***meteors.*** More than one hundred million meteoroids on the average are estimated to enter earth's atmosphere within a period of 24 hours, adding about ten tons of material to earth.

The luminous appearance, in the shape of a long line in Earth's atmosphere comes, not from the falling particles or rocks themselves, but from the effect produced by them in the atmosphere as they plunge downwards. When a meteoroid enters the Earth's atmosphere at high speed (upto 70 km/s), the collision of the meteoroid with air molecules produces frictional heating, which normally vaporises the particle completely. The vaporised atoms from the meteoroid collide with more air molecules. The energy of the collisions ionises them.

This ionisation forms a long trail of positively charged ions and negatively charged free electrons behind the meteoroid. Within a fraction of a second, the ions and the electrons recombine, giving off light. A typical meteor trail occurs at heights of 80 to 100 km above the Earth's surface.

Most of the meteoroids are vaporised by the heat generated due to friction in the Earth's atmosphere. However, pieces of a bigger meteoroid may survive and fall on the Earth's surface producing a ***crater*** with a big flash of light and explosive sounds. The remains of meteoroids which actually land on the surface of the Earth are called *meteorites.*

This crater on Earth gradually erodes and disappears by winds in the atmosphere. A few recent ones, which have not yet eroded, can be seen and usually make places of tourist interest, e.g. the Lonar lake near Mumbai.

INTEXT QUESTIONS 36.6

1. *What are asteroids? Where in the Solar System is the belt of asteroids located in which most of the known asteroids are there?*

   ....

2. *What are Comets? What is the shape of their orbits? What are they made of?*

....

3. *Why is a Comet not visible when far away from Sun? What is 'coma' or 'head' of a comet?*

....

4. *Differentiate between a meteoroid, meteor and meteorite. Is the long line of light, that we see as shooting star, the light coming from the hot falling meteoroid?*

....

5. *Name a large meteorite crater in India. Where is it located?*

....

36.8 EVOLUTION OF THE SOLAR SYSTEM

How did our Solar System evolve? Any theory which attempts to explain the evolution of Solar System must explain the following features:

1. (a) The Sun has 99.9% of the mass of Solar System, but (b) planets have 200 times as much angular momentum as the Sun.
2. All planets and most of their satellites move in roughly same plane and revolve and rotate in the same direction.
3. Gas giants (Jovian planets) are roughly 100 times as massive as the terrestrial planets.

According to all modern ideas about formation of planets, these planets are a by-product of the formation of the stars. Thus in the case of our Solar System, the Sun and the planets were formed nearly simultaneously about 4.5 billion years ago. There existed a central condensation – the Sun – formed by the gravitational contraction of a cloud of gas, containing hydrogen, helium and other elements. The heavier elements were earlier cooked up in a previous star, which exploded and contributed its matter to that cloud.

A small part of the cloud – the outer layers made up of gas and dust, formed rapidly into a flattened disc rotating with the central condensation. This disc is called **Solar nebula** (Fig.36.13). Such discs can develop during formation of many stars from which their planets can develop and are therefore called ***protoplanetary discs.*** The Hubble space telescope has, infact, recently photo-

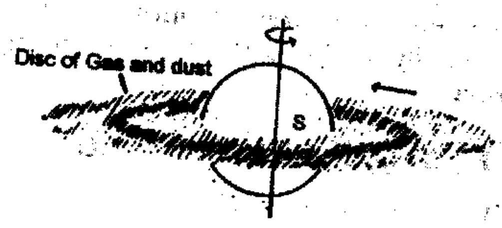

Fig. 36.13 *: Solar nebula*

graphed such discs around many developing stars in ***Orion constellation.*** This process takes care of feature (2) and 1(a) mentioned above.

In the 1970's a Soviet astronomer named Safronov developed the theory of the formation of the planets by means of ***collisional accretion,*** which is considered most reasonable now-a-days. Collisional accretion means combining of two small pieces by gravitation when they come together, thus forming a larger piece. According to this theory the planets were formed in three stages.

In the initial phase, which was very rapid (about 1000 years), small solid, ***planetoids*** or ***planetesimals*** (size below 5 kilometers) were formed, as a result of small-scale gravitational instabilities in the solid dust grains present in the nebula (Fig.36.14(a)). Due to their random

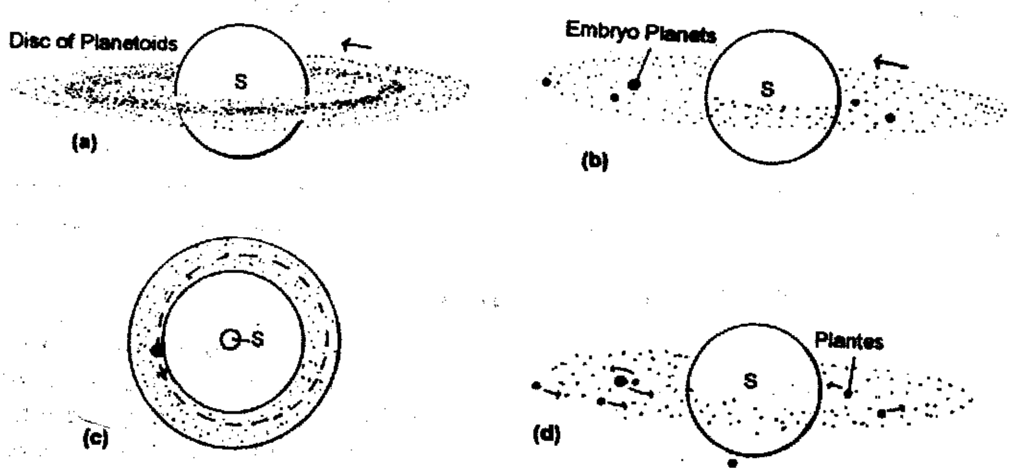

Fig. 36.14: *(a), (b), (c)*

distribution, wherever dust grains happen to be more concentrated, they come together by gravitation and then attract more grains in nearby space, thus forming a planetoid.

In the intermediate phase embryo planets of about 1000 kilometre size where formed (Fig.36.14(b)). This took more than 100 million years. At the end of the first phase, the protoplanetary disc was composed of a relatively homogeneous mass of little planetoids revolving round the Sun. These objects encountered each other frequently. When two planetoids make a close encounter then there are two possibilities:

(a) If the relative velocity of approach is large, ***collisional breakup*** takes place. The collision completely destroys the objects. The fragments are added to the planetoids.

(b) If, on the other hand, the velocity of approach is small, the two objects fuse and remain together, as a result of their mutual gravitational attraction. A single body of bigger size is thus created. This process is ***collisional accretion.***

In the final phase, embryos grew into planets (Fig.36.14(d)). This phase took hundreds of million years. It has been theoretically established that when some objects have grown to a size of between 1000 km and 2000 km, their subsequent growth no longer depends upon the chance encounter. Because of their large size and mass, their gravitational spheres of influence extend far beyond their diameters. If a small planetoid enters such a region, its orbit will be strongly perturbed, with a strong probability that it will be "swallowed" by the embryo (Fig.36.14(c)).

However, inspite of recent progress in the field of science and technology, all the features of our Solar System are not yet well understood.

INTEXT QUESTIONS 36.7

1. *What is meant by Solar nebula? What is the recent experimental evidence that the planets developed from Solar nebula?*

   ....

2. *What are planetoids? How are these thought to have been formed in the beginning of the Solar System?*

   ....

36.9 WHAT YOU HAVE LEARNT

- The Sun is a huge ball of gas. At its surface it is hotter than anything that we have on Earth. Thus it radiates in all parts of electro-magnetic spectrum. Due to its huge mass, Sun is practically at rest and all other objects in the Solar System revolve around it.
- That the visible surface of Sun, the photosphere is a thin layer of gas with million of granules which transport heat to outer most layers.
- Solar atmosphere consists of a reversing layers which cause absorption lines in the spectrum of sunlight, chromosphere and corona, which can be seen only when brilliant photosphere is hidden by Moon during total solar eclipse;
- Nine planets revolve around Sun in nearly co-planner and nearly circular orbits, except for pluto;
- Radius and time period of all objects revolving around a heavy object are related by keplers' III Law. Knowledge of r and T of any of them enables us to find mass of that heavy object;
- That maximum elongation of an inferior planet enables us to find the radius of its orbit;
- Motion of conducting fluids inside Earth or Sun, which are also rotating about their own axes, caused them to have a magnetic field similar to that of a bar magnet.
- That temporary dark spots (sunspots) are formed on the surface of

sun which are cooler than surrounding photosphere. These have intense local magnetic field in their central portion. These spots on the otherwise featureless surface of Sun enable us to observe rotation of the Sun. Their number keeps on increasing and decreasing in a roughly 11 year cycle;

- That solar flares, i.e., explosive out-bursts of electromagnetic waves and charged particles from the surface of Sun, frequently occur, more frequently during sunspot maxima.
- That flame like masses of bright gas frequently rise hundred of thousands kilometers above Solar surface, which can be seen as prominances at the limb of Sun during a total Solar eclipse.
- That lacs of minor planets, called asteroids, revolve around Sun. These are found everywhere in the Solar system but most of them are in a belt between the orbits of Mars and Jupiter.
- That tiny objects composes of ices and dust revolve around Sun, in very elongated orbits. These are called comets because, as one comes close to Sun, the ices sublimate giving it a huge size and a tail pointing away from the Sun.
- That meteoroids ranging in size from a grain of sand to tens of metres are also orbiting the Sun. Hundreds of Millions of them enter Earth's atmosphere every 24 hours. Most of these evaporate by frictional heating in air making streaks of radiance.
- That the planets and other objects in the Solar systems evolved as a by-product of the process of formation of Sun from a cloud of gas and dust. First Solar nebula — a flat disc of gas and dust was formed around Sun. Then planets were formed in this disc by the process of collisional accretion.

36.10 TERMINAL QUESTIONS

1. When can we look directly at Sun without damage to our eyes? What changes take place in the Sun light before reaching our eyes at that time?
2. A telescopic camera is improvised using a spectacle lens of focal length 200.0 cm. Full moon is photographed. Diameter of image of moon on the film is 16.7 mm. Find the angular diameter and distance of moon at that time. Diameter of moon is 3476 km.
3. When can we observe the chromosphere? Why is it seen for a very short time only?
4. An artificial satellite is revolving around Earth, making one revolution in 24 hours. It is at a height of 36000 km above the surface of Earth. Find the mass of Earth.

   ($G = 6.7 \times 10^{-11}$ $Nm^2\ kg^{-2}$, diameter of Earth = 12750 km; you may give correct fraction only and need not make long calculations to get final value).
5. Mercury makes one revolution around Sun in 87.97 days and Earth

in 365.25 days. How much time will Mercury take to make one revolution more than Earth, i.e. after a conjuction with the Sun it will make the next conjuction with the Sun.

6. Maximum elongation of Mercury is observed to be 28°. Find radius of its orbit around sun in AU and in km.
7. What does a solar flare send on Earth? What protects the life on Earth from harmful effects that solar flares could cause?
8. How canbwe observe that Sun is rotating about its axis?
9. How does the number of Sun-spots on the solar disc change with time?
10. When do the solar flares occur more frequently on the Sun? How is their location related to sunspots? What energises solar flares?
11. What is aurora borealis? How is it caused?
12. What are umbra and penumbra of a sunspot? Roughly how much cooler or hotter are they than surrounding photosphere?
13. (a) Roughly how strong is the magnetic field in the umbra of a large sunspot, as compared to that on Earth? (b) How does this magnetic field help the sunspots to stay on for long periods of time?
14. At what inclination to its axis of mechanical rotation is the magnetic axis of (a) Earth, (b) Sun?
15. In which direction are asteroids revolving around Sun? Why are all of them revolving in the same direction around Sun according to the theory of evolution of Solar System?
16. Are there asteroids whose orbits cross the Earth's orbit? What is the implication of such asteroids for life on Earth?
17. What are periodic Comets? Name one periodic comet and state its period of revolution around the Sun.
18. When does a comet develop a 'tail'? What is its direction?
19. How does atmosphere protect us from the bombardment of falling meteoroids? How many of them are estimated to fall on Earth in 24 hours?

CHECK YOUR ANSWERS

Intext Questions 36.1

1. Refer article 36.3 para 3
2. Refer article 36.3.1 para 1
3. Angular diametre of Sun $\frac{3\,cm}{3.2\,m} = 9.4 \times 10^{-3}$ radian diameter of Sun = distance x angular diameter.

Intext questions 36.2

1. Refer article 36.4.2 para 1
2. Refer article 36.4.3 paras 3 and 4
3. Refer article 36.4.3 para 2

Intext questions 36.3

1. Refer article 36.5
2. Refer article 36.5.1
3. Use Kepler's III Law in the form

$$\frac{GM}{4\pi^2} = \frac{r^3}{T^2} \Rightarrow M = \frac{4\pi^2}{G}\frac{r^3}{T^2}$$

Where $r = 1.5 \times 10^{11}$m, $T = 365.25 \times 24 \times 60 \times 60s$

4. After a conjuction with Sun let the Venus make next conjunction after n days. During this time Venus makes one revolution more than Earth. Hence,

$$\frac{n}{224.70} - \frac{n}{365.25} = 1$$

Solve this equation to obtain the value of n.

5. Radius of the orbit of Venus = $\sin \epsilon_{max}$ A.U.

= $\sin 48^\circ$ A.U.

= 0.743 A.U.

Convert this value to metres using the relation 1 A.U. = 1.5×10^{11} m.

Intext questions 36.4

1. Refer article 36.6.4 paras 1 & 2
2. From the year 1705 to year 1968, the time interval is 263 years. Number of sunspot cycles which occurred in 263 years.

$$= \frac{263}{11} = 24 \text{ (approximately)}$$

Since we can take a sunspot cycle to be from one sunspot maximum to next, there occurred approximately 23 sunspot maxima between 1705 and 1968.

Note : Though result calculated above is actually exact, it must be emphasised that time period of sunospot cycle is not a standard value. It keeps varying. Hence, above kind of calculation cannot always give the correct number.

3. Refer article 36.6.1 para-2

Intext questions 36.5

1. Refer article 36.6.5 para 1.
2. Refer article 36.6.4 para
3. Refer article 36.6.7 paras 1 & 4.

Intext questions 36.6

1. Refer article 36.7.1 para 1.
2. Refer article 36.7.2 paras 1 & 2.
3. Refer article 36.7.2 para 3.
4. Refer article 36.7.3 paras 1 & 2.
5. Refer article 36.7.3 para 5.

Intext questions 36.7

1. Refer article 36.8 para 3.
2. Refer article 36.8 para 5.