UNIT 11 THE SOLAR SYSTEM

Structure

11.1 INTRODUCTION

In Unit 10 we have described some modern astronomical methods of exploring the universe. You also studied some theories about the origin of the universe and stellar evolution, which explain many observations and data gathered in these explorations. While reading Unit 10 you must have realised that our knowledge of the universe is rather imperfect. In fact, every new answer opens up many new questions about the universe. However, there is one tiny part of this vast and ancient universe that we know a little better. This is the Solar System, of which our planet Earth is a part.

In this unit you will read about the Solar System. We will describe the currently available knowledge of the Solar Family, the special characteristics of its members and the formation of the Solar System. Within the Solar System, we know more about the Earth and its satellite Moon than its other members. Therefore, we will give a detailed description of these two.

We now know a lot more than our ancestors did about the planetary motions. Yet, people harbour many myths and misconceptions about the planets' influence on their daily lives. We will analyse, in brief, why it is so and try to show the irrationality of such notions. With this unit we will end our discussion about the universe. In Unit 12 you will read about the origin and evolution of life, which makes an equally fascinating story.

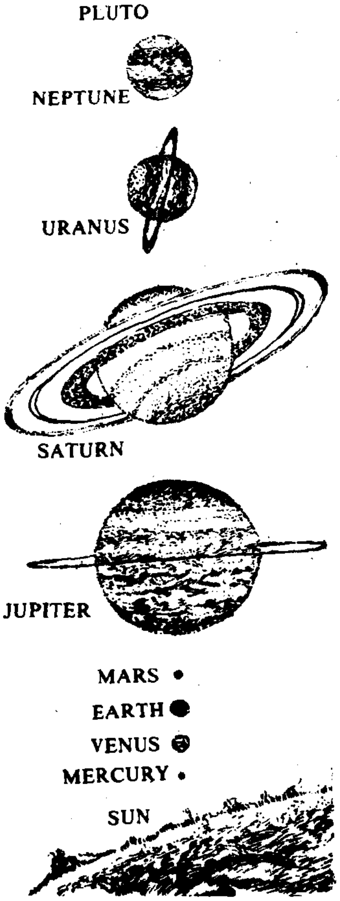
Objectives

After studying this unit, you should be able to:

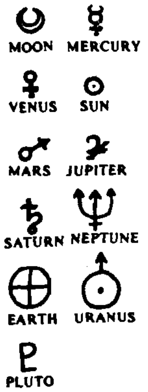
- describe the main characteristics of the various members of the Solar System, i.e., the Sun, planets, their satellites, asteroids and comets,
- explain how the formation of the Solar System may have taken place,
- describe the origin and early history of our planet Earth,
- analyse the myths and misconceptions about the effect of planetary motion on human lives.

11.2 THE SOLAR SYSTEM: A GENERAL SURVEY

At night you can see very many stars in the sky. But during the day, only one star is visible, and that is the Sun. This is not because there is anything extraordinary about it but because it is the star closest to us. The light of the other, more distant stars is too feeble to be seen during the day time. The Sun's apparent magnificence had led ancient civilisations to think of it as the 'head' of the universe. Actually, it is only the 'head' of its own family, known as the Solar System. This family consists of nine planets, including the Earth, their satellites, asteroids and comets. Arranged according to their increasing distance from the Sun, the nine planets which go around the Sun are: Mercury (*Buddha*), Venus (*Shukra*), Earth (*Prithvi*), Mars (*Mangal*), Jupiter (*Brihaspati*), Saturn (*Shani*), Uranus (*Arun*), Neptune (*Varun*), and Pluto (*Yama*), (Fig. 11.1). Except for Mercury and Venus, all the planets have big and small satellites going around them. There are also countless asteroids and comets in orbit around the Sun.



(a)

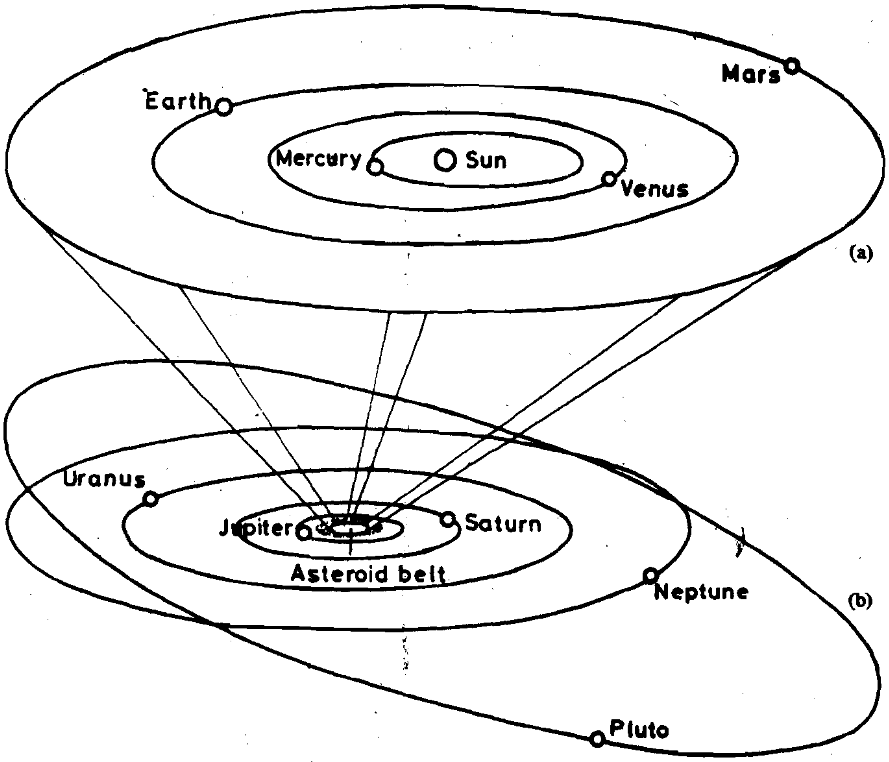


(b)

Figure. 11.1: (a) Solar System showing the relative sizes of planets; (b) symbols depicting some members of the Solar System.

All the planets and asteroids, and some comets, revolve around the Sun in elliptical orbits (see Fig. 11.2). They all orbit the Sun in nearly the same plane. You can make a fairly accurate model of the Solar System from a single piece of cardboard on which you can draw the planetary orbits.The only exception of this model is the orbit of Pluto, which is inclined at an approximate angle of 17° to the general plane of the Solar System. The North Pole of the Earth determines the 'north side' of the Solar System. Seen from the "north side", all planets revolve around the Sun. Its gravitational attraction keeps them revolving in their orbits. If the Sun were to suddenly vanish, the planets would all fly off in straight lines at a tangent to their orbits.

The Sun is the dominating member of the Solar System. With a mass calculated to be approximately 2×10^{33} g (grams), it contains almost 99.87% of the mass of the entire Solar System. Of the nine planets, Jupiter and Saturn are the most massive, accounting for 92% of the mass of all planets. The planets do no generate their own light, like the Sun does. They shine by reflecting the Sun's light that falls on them. The percentage of sunlight reflected by any object is directly related to the amount and type of atmosphere that it possesses. Planets or satellites with no atmosphere, such as Mercury and Moon reflect less light. The Moon appears so bright to us because of its nearness to the Earth.



Figure, 11.2: Planetary orbits of (a) inner planets scaled up; (b) outer planets.

All planets, except Venus and Uranus, rotate on their axes in the anticlockwise direction. So, on all these, like on the Earth, the Sun rises in the east and sets in the west. Venus and Uranus rotate in a clockwise direction and as a result, on these two planets the Sun rises in the west and sets in the east! All planets except Uranus have their axes of rotations more or less perpendicular to the plane of orbits (see Fig. 11.3). The axis of rotation of Uranus is in its orbital plane, as though Uranus had toppled over.

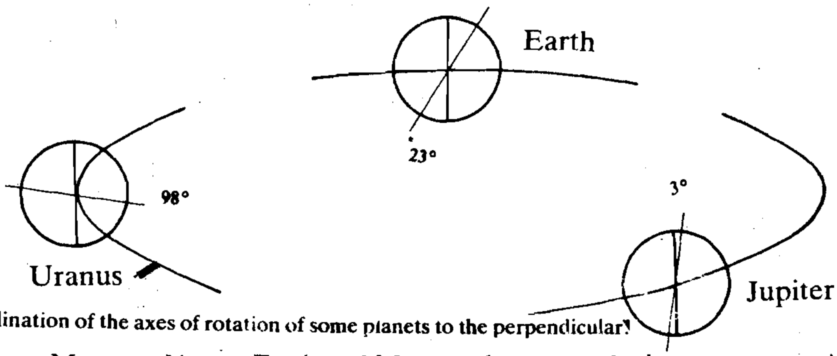


Fig. 11.3: Inclination of the axes of rotation of some planets to the perpendicular

The four planets, Mercury, Venus, Earth and Mars are known as the inner or terrestrial (i.e., earth-like) planets. Jupiter, Saturn, Uranus, Neptune, and Pluto are the outer or Jovian (i.e., Jupiter-like) planets. There is a clear division in the properties of the inner and the outer planets. The inner planets consist mostly of metals and rocks and have an average density of 4 or 5 g/cm^3 (read as grams per cubic centimetre). The asteroids are also like the inner planets in composition. The outer planets, on the other hand, are mostly gas and ice with an average density of 1 or 2 g/cm^3.

SAQ 1

What objects constitute the Solar System?

....

This is a general survey of the Solar System. Let us now look at each of the members in some detail. We begin with the head of the family, the Sun.

11.3 THE SUN, A MODEL STAR

The Sun is the most important star from our point of view. It is the only star close enough to be studied in considerable detail. The grandeur of the Sun is partly because of its size. Its diameter is almost 110 times that of the Earth. We can best visualise the volume of the Sun if we realise that more than a million earths can be dropped into the space it occupies. As we have said above, the mass of the Sun is about 2×10^{33} grams, which makes it more than 300,000 times the mass of the Earth. The average density of the Sun, i.e., its mass per unit volume, is about 1.4 g/cm^3. You may answer the following questions to refresh your memory of what you've read about the Sun as a star in Unit 10:

SAQ 2

Give short answers in the space provided.

a) What is the Sun largely made up of? ....

b) What is the source of the Sun's energy? ....

c) For how many years will the Sun keep 'burning' like this? ....

d) What stages of evolution will the Sun follow, once its source of energy gets exhausted? ....

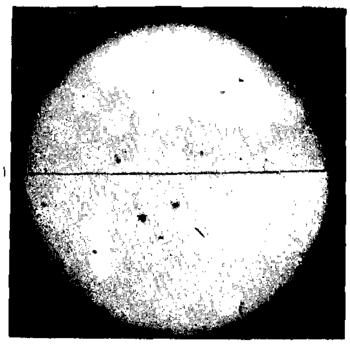


Fig. 11.4: Sunspots on the Sun's photosphere.

Although the Sun appears to be unchanging, it rotates about its axis once every 25 days. From time to time dark patches appear on the surface of the Sun, usually in pairs or in groups. These dark patches are called **sunspots**. Their movement is an indication of the Sun's rotation. This fact was recognised for the first time by Galileo. Actually, a sunspot is a region on the surface of the Sun that consists of gases almost 1000°C cooler than those surrounding the area (Fig. 11.4). The number of sunspots increases and decreases in a cycle every 11 years. In the long term, there are periods of low number of sunspots and high number of sunspots.

Layers of the Sun

The Sun's body is made up of several layers. The layer that forms the visible surface of the Sun is called the **photosphere**—it is the surface that demarcates the body of the Sun and its atmosphere. When we talk of the diameter of the Sun, we are referring to the diameter of the photosphere. The temperature of the photosphere is about 6000°C. The innermost layer of the Sun is its **core** where its energy is produced through nuclear reactions. There are other layers between the core and the photosphere which we will not describe here.

Like the Sun's body, the solar atmosphere too has several layers. The outermost layer of the Sun's atmosphere is called the **corona**. Normally, the corona cannot be seen due to the brilliance of the photosphere. However, if it is seen during a total solar eclipse, it is visible in its full glory (Fig. 11.5). The corona extends all the way upto the Earth's orbit and even beyond.

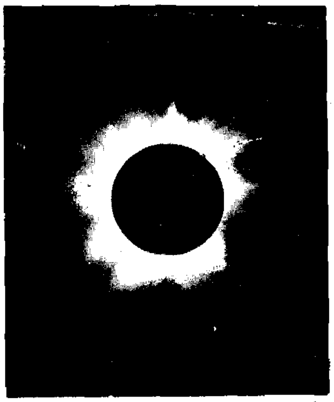


Fig. 11.5: Solar corona seen at the time of total solar eclipse.

Solar Wind and Solar Flare

Most of the Sun's family is continually bathed in an outflow of material from the Sun's atmosphere. Streams of electrons and protons continuously flow out from the Sun's atmosphere and travel across the Solar System. This rapidly moving stream of charged particles is called the **solar wind**. About one million ton material is removed every second from the Sun in the form of the solar wind. These charged particles react with the atoms of the Earth's atmosphere to produce northern lights, 'aurora borealis' at the North Pole and southern lights, 'aurora australis' at the South Pole. This display of lights in nature, is truly spectacular.

The **solar flare** represents the most dynamic activity associated with the Sun's surface and atmosphere. It represents a tremendous release of energy in a very short time. Usually it occurs in the neighbourhood of a sunspot. There is a sudden brightening accompanied by a violent outflow of energy in the form of light, radiowaves, X-rays and solar material like electrons and protons.

The Sun is our nearest star and we have been able to examine it quite closely. We have just presented some salient features of the Sun's structure and its activity. You may like to try the following SAQ before studying about the other members of the Solar System!

SAQ 3

a) What observation indicates that the Sun rotates?

....

b) Which phenomena indicate the activity of the Sun?

....

....

11.4 THE PLANETS, ASTEROIDS AND COMETS

In this section you will read about the planets and their satellites, asteroids and comets. We will not consider the Earth and the Moon here as we plan to take a detailed look at them in the next section. In Table 11.1, we list some of the space probes that have been sent to the planets. They have revealed a lot of information about the surface features, temperature, atmosphere etc. of the planets. If you want to know more details, you may study the books listed at the end of this block.

Table 11.1

Planets probed:	Mercury	Venus	Mars	Jupiter, Saturn, Uranus, Neptune, Pluto, Saturn's satellite Titan
Space probes:	Mariner series	Venera, Mariner, Pioneer Venus Mission	Mariner, Viking, Mars	Voyager, Pioneer
Observations made: Surface features of the planets, atmospheric conditions, chemical composition, temperature				

11.4.1 Mercury—the Elusive Planet

Mercury, the planet nearest to the Sun, has long remained a mysterious body. Because of the Sun's glare, it is difficult to see it clearly all the more so because it is very small.

Mercury appears for a brief time as a morning object in the eastern sky, rising just before sunrise. Then it can be briefly seen as an evening object in the western sky, setting just after sunset. Even through the largest telescopes in use today, Mercury appears less distinct than the Moon does to the naked eye.

Photographs of the surface of Mercury show craters and wrinkles on it, separated by substantially large smooth areas (Fig. 11.6). Mercury possesses no atmosphere. It has a temperature of almost + 427°C on the side facing the Sun to a low of almost −270°C on its dark side. It has no satellite.

A planet is called a morning object if it is seen just before sunrise; if it can be seen after the sunset, it is called an evening object.

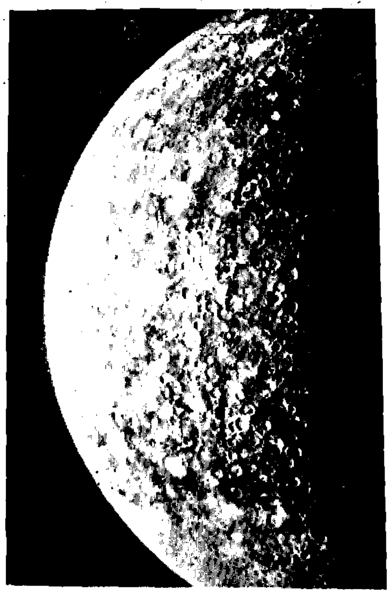


Fig. 11.6: Mercury.

Fig. 11.7: Venus.

11.4.2 Venus—the Clouded Planet

Venus, our nearest planetary neighbour, only 40 million km away, has its surface hidden from view by a dense yellowish-white cloud, which extends to 80 km above the surface (Fig 11.7). Venus appears to be the third brightest object in the sky after the Sun and the Moon, because of its short distance from us and because the white cloud reflects almost 76 per cent of the sunlight that falls on it. Venus appears so bright at times that, under ideal atmospheric conditions, it may be seen with the unaided eye in daytime. Venus can be best seen about three hours after sunset when it is a night object or about three hours before sunrise when it is a morning object. As you have read in Unit 9, Venus appears to go through phases, quite like those of the Moon. It requires almost 20 months for an observer to see Venus in all its phases.

As revealed from the space probes, Venus has turned out to be a broiling hot planet. The surface temperatures of Venus are around 480°C. The atmosphere of Venus is made up of 96 per cent carbon dioxide gas and clouds of sulphuric acid with small quantities of hydrochloric and hydrofluoric acid. There are small traces of water vapour, nitrogen, argon, sulphur dioxide and carbon monoxide gases. The atmospheric pressure is 90 times the pressure we feel from the Earth's atmosphere. With its searing heat, crushing pressures and poisonous gases, Venus seems less the goddess of love of mythology and more an incarnation of hell! Life cannot survive on Venus.

The high surface temperature of Venus comes about through what is known as the **greenhouse effect**. Sunlight passes through the clouds and atmosphere of Venus, and reaches its surface. The surface on being heated, gives out infrared radiations. The carbon dioxide in the atmosphere of Venus does not let the infrared radiation escape. Thus, the heat of the Sun is efficiently trapped with only very little being able to escape. As a result, the surface temperature rises.

Now that human beings have unveiled the mysteries of the clouded planet, many imaginative ideas have been put forward to turn Venus into a habitable planet. One idea is to introduce small living organisms, which can consume carbon dioxide and give off oxygen, into the planet's atmosphere. So, as time passes, the greenhouse effect will become less as carbon dioxide gas decreases in the atmosphere. This will cool the planet's surface, and water vapour will condense. As rain falls, the heat-retaining clouds will begin to clear. This will create a planet with an oxygen-rich atmosphere and a cool temperature to sustain a variety of life forms. It may even become suitable for human beings to live! This may seem like a fantasy today. But, there are plausible elements in this idea and it might become a reality in the not so distant future!

11.4.3 Mars—the Red Planet

After Venus, **Mars** is our closest neighbour. It seems very earth-like. There are ice-caps on its poles, drifting white clouds and raging dust storms in its atmosphere. Seasonally changing patterns occur on its red surface. There are large dark areas on its surface called maria (meaning 'seas'). It even has a twenty-four-hour day. Mars experiences summer and winter seasons, each of which lasts for almost six earth months. However, the planet's distance from the Sun causes these seasonal changes to be more extreme.

It is tempting to think of Mars as an inhabited world. In 1877, the Italian astronomer, Schiaparelli, observed an intricate network of single and double lines criss-crossing the bright areas of the planet Mars. He gave them the name of canali. Canali in Italian means channels or grooves. But it was promptly translated into English as 'canals'. Since then, people have wondered who had made these canals and how. Were there living beings on the planets?

Fig 11.8: The surface of Mars.

Many satellites have now been sent into orbit around Mars. Two automated laboratories have been landed on its surface. The entire planet has been mapped. Martian surface has craters of all sizes, ranging from 5 km to 121 km in diameter, created by meteorite impact (Fig. 11.8). It also has enormous volcanoes. The largest volcano on Mars, Olympus Mons or Mount Olympus is nearly three times as high as Mount Everest. It is not active any more. The Martian surface has deep ridges and valleys. Pictures also show islands made where water once flowed around the existing craters, and river beds, dry for hundreds of millions of years. The surface features indicate that Mars may have had both atmosphere and ocean in the past. Viking space probes, send by U.S.A., did find evidence that liquid water once flowed on the planet and the atmosphere was also more dense than what it is now. Martian soil is mostly like the Earth's soil made up mainly of silicates. However, about 16 per cent of the soil is made up of iron oxide, giving it its red colour.

The atmospheric pressure on Mars is very low. It is comparable to what it is on the Earth at a height of 32 km from sea level. Thus, Mars has a very thin atmosphere. It is made up of 95 per cent carbon dioxide. The rest is nitrogen, argon and a small amount of water vapour. Tiny amounts of hydrogen, oxygen and ozone have also been detected. Though Martian atmosphere has clouds of frozen water, carbon dioxide and of reddish dust, it does not contain enough gases to trap the Sun's heat. This makes Mars a very cold planet. The surface temperature may rise to 21°C or 27°C near its Equator, at noon. But, during the night, it becomes as low as −84°C. The present conditions on Mars—cold, extreme dryness, intense ultraviolet light and little oxygen—are hostile to the familiar forms of life. The Viking experiments on Mars showed no signs of life.

Silicates are compounds made up of silicon, oxygen and some other metal, such as aluminium, calcium etc.

Mars possesses two natural satellites. They are called Phobos (Fear) and Deimos (Terror). Phobos, about 27 km in diameter, is about 9,300 km away from Mars. Deimos is even smaller, about 14 km in diameter. The latter is 24,000 km from the surface of Mars. More information about Mars and its satellites is expected in the near future from the Soviet Union's space missions to the planet.

11.4.4 The Asteroid Belt—Rubble of the Solar System

There is a gap of 547 million kilometers, between the orbits of Mars and Jupiter. In this gap are thousands of bodies made of rock and metal, ranging in size from mere specks of dust to hundreds of kilometers. These are called **asteroids**, and are believed to represent original solar material which failed to bind together to form a planet. The first asteroid was discovered in 1801 by Giuseppi Piazzi, who named it Ceres. It is 960 km across. The number of asteroids known now runs into thousands.

Most asteroids are irregular in shape. They reflect varying amounts of light as they travel through space. Their shapes suggest that they may be the product of a collision or an explosion. Thousands of fragments of asteroids enter the Earth's atmosphere every year, producing a streak of light across the sky. This streak of light shooting across the sky is called a **meteor**. Of the objects that enter the Earth's atmosphere, many are of the size of a grain of sand or a pebble and they are destroyed in flight. The objects that are large enough to survive the flight and hit the Earth's surface are called **meteorites**. A meteorite is like a piece of the Solar System right in our laboratory. The chemical analysis of meteorites provides us vital information about the Solar System.

Thus far, we have described some characteristics of terrestrial planets, except the Earth and its satellite Moon. You will now study some features of the Jovian planets and the comets. But how about trying the following SAQ first.

SAQ 4

Give short answers in the space provided.

a) Why does Venus reflect so much more light than Mercury or Mars?

....

b) What features of Mars make it similar to the Earth?

....

c) Why have we called the asteroids as the rubble of the Solar System?

....

d) What is the difference between a meteor and a meteorite?

....

....

11.4.5 Jupiter—A Strange Veiled Giant

Jupiter is the largest planet of the Solar System. If Earth were placed on the face of Jupiter, it would look like a 50 paise coin on a dinner plate. It weighs more than twice as much as all the other eight planets put together. It has sixteen known satellites. Jupiter is not only the biggest planet but also the liveliest. It is full of mysteries and surprises. Its highest clouds are mainly crystals of frozen ammonia gas at a temperature of about $-140^{\circ}C$. It is veiled in a turbulent, gaseous atmosphere made up of hydrogen and helium with significant amounts of ammonia and methane. The atmosphere reaches thousands of kilometers deep to the surface. It gradually thickens into a churning liquid due to the immense pressures scientists assume that it finally turns into a liquid metallic core. At its centre, Jupiter has a small rocky core where temperatures probably reach 20,000°C, about three times the temperature of the Sun's surface. There may also be iron, silicon and other heavy elements in the rocky core. Jupiter seems to be more like the Sun in its composition than the other planets.

(a)

(b)

Fig. 11.9: (a) Jupiter; (b) the Great Red Spot of Jupiter.

The most outstanding feature on the surface of Jupiter is the Great Red Spot shown in Fig. 11.9 (b). It is a long oval area which is so huge that two earths, side by side, could be dropped through it. Sometimes it becomes pale pink in colour and at other times a fiery orange red. For long, the Great Red Spot puzzled the astronomers. The Pioneer and Voyager missions to Jupiter revealed that the Red Spot is a huge cyclonic disturbance in the atmosphere.

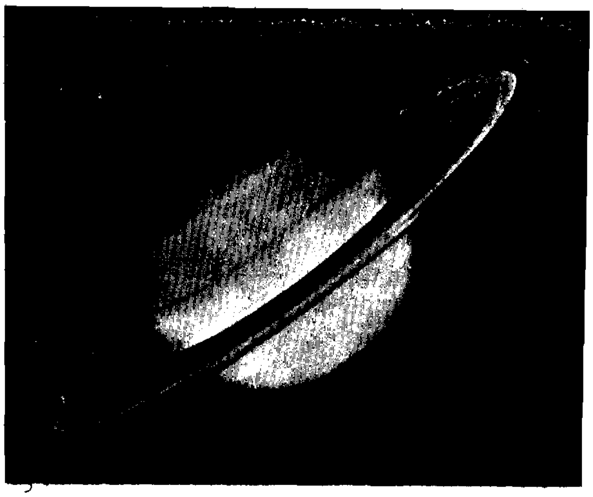
Jupiter is mainly a quick-spinning ball of gas and liquid with no solid surface. It also emits radio waves. Its composition, size and the number of moons gave rise to the idea that Jupiter is not a planet but rather a star with a "solar system" of its own, that did not start 'burning'. It is estimated that if Jupiter were just ten times heavier, it could have started to produce its own energy like the Sun.

Jupiter's four largest satellites, Io, Europa, Ganymede and Callisto are called the Galilean satellites after Galileo, their discoverer. They are fascinating worlds in themselves. Io, of diameter 3240 km, is almost like a fireball with frequent volcanic eruptions. Beyond Io are Europa, diameter 3120 Km, Ganymede, diameter 4900 km and Callisto, diameter 4570 km. Europa is thought to be made up of frozen ice. Ganymede and Callisto have a thick icy covering on them. The remaining satellites of Jupiter have not been so well studied.

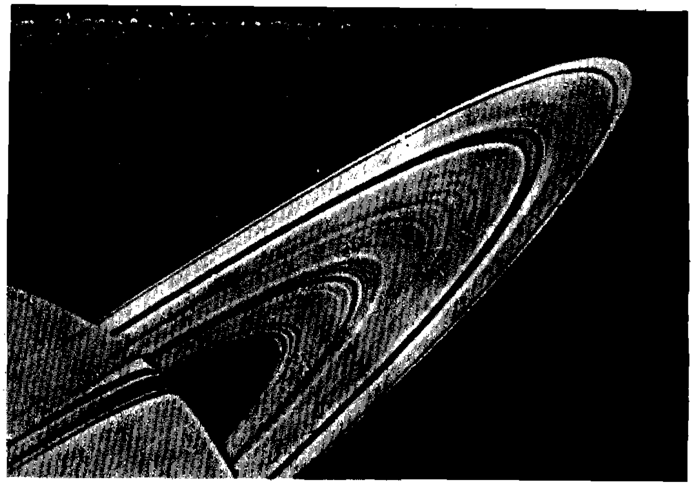
With ammonia clouds, intense emission of radio waves, enormous storms and satellites of fire and ice, Jupiter seems to be a most unlikely place to find life. Yet, in some ways, conditions on the present day Jupiter are not very different from those that did produce life on Earth about four billion years ago. Water, ammonia and methane, considered essential to the formation of life, are all present in the atmosphere of Jupiter. Moreover, lightning bolts continuously flash through Jupiter's clouds. Even if only a few organic compounds are found to exist on Jupiter, it will strengthen the idea that life is a normal phenomenon throughout the universe.

11.4.6 Saturn—the Ringed Planet

Saturn, the sixth planet, is the last one visible to the naked eye. Its rings, visible only through a telescope, make it the most striking and beautiful sight in the Solar System (Fig. 11.10). On seeing Saturn through his telescope, Galileo described the planet as having ears! These were actually three rings that girdle Saturn's equator. It is the second largest planet, exceeded in size and mass only by Jupiter. Saturn is colder than Jupiter. The temperature at the top of its clouds is -180°C. Like Jupiter, Saturn consists mainly of hydrogen and helium, with traces of ammonia, methane and other compounds. Its average density is less than that of water. Thus, if we could put Saturn in a large enough ocean, it would float!



(a)



(b)

Fig. 11.10: (a) Saturn; (b) the rings of Saturn.

The rings of Saturn are its most distinctive feature, giving it a matchless grace. The rings are in fact a thousand tightly packed individual ringlets, like the grooves on a gramophone record. Even the supposed gaps in the rings have been found to contain small particles. Most astounding of all, a new outermost ring contains two strands twisted around each other like the threads of rope. The rings are made up of large chunks of solid matter—probably ice coated rocks.

Saturn, too, has at least 16 satellites orbiting it at the edge of the rings. The close-ups of the known satellites reveal that they are icy and heavily cratered by the impact of meteorites. Saturn's main satellite is Titan, 5800 km in diameter. It is large enough to have been a planet by itself. It is the only satellite in our Solar System which has an atmosphere nearly as dense as our own. Its atmosphere is made up of 90 per cent nitrogen gas and organic compounds such as hydrogen cyanide. But it is a very cold world, with a surface temperature of −184°C. It is far too cold for any life as we know it, apart from having the highly poisonous hydrogen cyanide.

11.4.7 Planets Beyond the Reach of the Eye

The remaining three planets Uranus, Neptune and Pluto, invisible to the unaided eye, were discovered later.

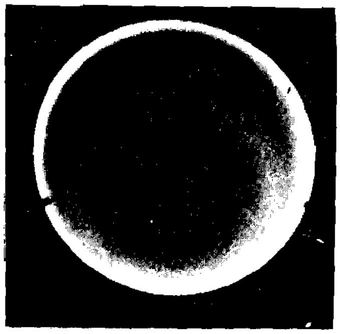


Fig. 11.11: Uranus.

Uranus

Uranus (Fig. 11.11) appears as a green disc with vague markings, even through the largest telescopes. Its colour is produced by the large amounts of methane and ammonia clouds in its outer atmosphere. The temperature of the ammonia clouds is about −217°C. Uranus is made up of gases such as hydrogen, helium and methane just like Jupiter and Saturn. Uranus is unique in the Solar System because its axis of rotation is tilted at an angle of 98° to the perpendicular and lies almost in the plane of its orbit around the Sun, with one pole sometimes pointing directly towards the Sun. It would seem that the planet has toppled over its side, rolling along the orbit like a wheel. Thus, the Sun shines directly on its poles. Uranus has fifteen satellites. In 1977, nine faint rings of rocky debris were also discovered around Uranus.

Neptune

The eigth planet, **Neptune,** was discovered in 1846 by astronomer Johann Gottfried Galle. We have already told you the story of its discovery in Sec. 8.3.4. It is so far away that, seen from Neptune, the Sun must appear just as a bright point. Neptune's atmosphere has methane but no detectable ammonia. Its cloud temperature is about −237°C. Neptune is orbited by Triton, one of the biggest satellites in the Solar System. It orbits Neptune in a clockwise direction, i.e. opposite to the planet's own rotation. It has an atmosphere of nitrogen and methane. It may even have an ocean of liquid nitrogen. Triton is accompanied by a smaller satellite, Nereid. In 1989, Voyager 2 passed within 35,000 km of Neptune and within 40,000 km of Triton resulting in a significant increase in our knowledge about Neptune and its satellites.

Pluto

Pluto's existence was also proposed to account for deviations in the orbit of Uranus. Even after the influence of Neptune had been accounted for, an American astronomer Percival Lowell, detected that the orbit of Uranus was still disturbed. Neptune's orbit too showed a similar disturbances. Lowell and Pickering did some calculations to predict the mass and radius of the orbit of Planet X which was supposed to cause these disturbances. In 1916, Pluto was discovered in about the right place in the sky. However, its mass turned out to be much smaller, about that of our Moon. Small, cold and dark, Pluto is about one-fifth of the size of the Earth. Its surface is coated with frozen methane. In 1978, a satellite of Pluto was discovered and named Charon. Not much is really known about Pluto.

W.H. Pickering was a Professor of Physics at Harvard University, U.S.A.

Pluto's orbit crosses that of Neptune's. No other planetary orbits cross in this way, and it is possible that Pluto is an escaped satellite of Neptune. Pluto's discovery had led astronomers to believe that it was the Planet X. But now calculations show that the mass of Pluto is too low to cause irregularities in Uranus' orbit. Thus, the search for the elusive Planet X goes on.

11.4.8 A Cloud Made of Comets

The cold outer areas beyond Pluto are the regions of **comets,** those visitors that dash around the Sun, seldom to be seen again. Comets are of great interest because they are the relics of the early history of the Solar System. When solar matter was churning and the Sun had just been ignited, its heat drove the lighter elements into the outer reaches of the Solar System. Hydrogen, oxygen, nitrogen and carbon collected into something like snowy cotton balls and they still float as a "cloud", at a distance of 100,000 times the distance of the Earth from the Sun! This thin cloud of comets reaches out to a distance halfway to the nearest star, i.e. almost a few billion kilometers.

Comets are made mainly of 'ices', that is ordinary water ice mixed with frozen gases such as methane, carbon dioxide and ammonia. The ices are mixed with specks of dust that makes them look like dirty snowballs. Billions of comets stay in their great cloud, moving slowly in enormous orbits around the Sun. While still in this cloud, comets do not shine. Once in a while the gravity of a passing star disturbs this cloud. A few comets then move into interstellar space and are lost to the Solar System. Others move towards the Sun.

Seen from the Earth, the comets shine more brightly than anything in the sky, except the Sun and the Moon. You may wonder how dirty looking snowballs turn into bright long-tailed comets. As a comet moves towards the Sun, its surface is warmed by the strengthening sunlight. Some of its frozen material turns into gas, forming a rapidly growing cloud called its **head** or **coma**, around its centre. On getting nearer to the Sun, more gas evaporates and its head becomes bigger and brighter. Also, a brilliant **tail**, made of dust and gas, is pushed out of the head by the pressure of the sunlight and the solar wind. This tail extends in a direction away from the Sun.

If comets pass very close to the Sun, they acquire enormous speeds, more than a million kilometers per hour, and move off into space with their tails pointing ahead. Most comets depart on long elliptical orbits, billions of kilometres into deep space, and remain there for thousands of years. But a few do not escape from the Sun so easily. If they happen to pass near a large planet, particularly Jupiter, its gravitation pushes them into short-period orbits around the Sun. One of the most famous comets is Halley's comet which returns once every 74 to 79 years (Fig. 11.12). It was last seen in 1986. Sometimes fragments from the comets fall on the Earth producing meteors. Comets returning repeatedly lose their gases each time. When all their ices melt, comets disintegrate, leaving a stream of small particles that spreads out thinly and loses its identity.

Fig. 11.12: Comet Halley.

SAQ 5

Give short answers in the space provided.

a) What properties of Jupiter make scientists think that it is more like a star which is not burning?

....

....

b) What feature makes Saturn appear distinct among the Jovian planets? What property of Saturn is demonstrated by the fact it would float in water?

....

....

c) What observations led to the discovery of Neptune and Pluto? Why is the search for Planet X still on?

....

....

d) What are the head and tail of a comet made of?

....

....

In this section we have tried to give you a bird's eyeview of the Sun's family, except the Earth and the Moon. Let's now take a closer look at our planet and its satellite, the Moon.

11.5 THE EARTH—THE MOST FAMILIAR PLANET

How do we describe the 'big ball' on which we live? Seen from space, it appears as a bluish-white sphere. Its wealth of plant and animal life, snow covered peaks, blue oceans and white clouds make the Earth a beautiful planet. Human beings have explored it extensively. Yet, the first hand knowledge of the Earth is limited to a thin shell of rock and water extending to a few kilometres below the surface, and to the atmosphere above. However, using indirect methods, such as the study of waves generated during earthquakes, scientists have been able to picture the Earth's interior, without ever seeing or sampling it. We will now briefly describe the current scientific knowledge about the Earth.

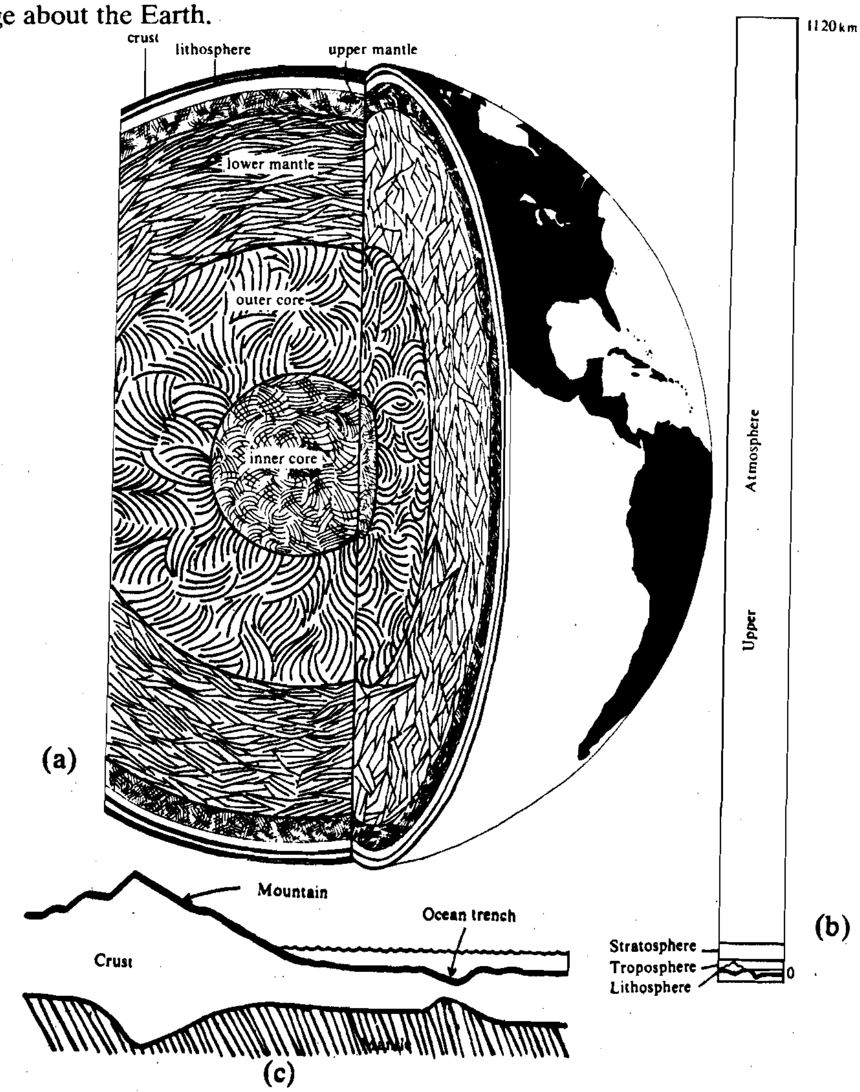


Fig. 11.13: (a) A cross-section of the Earth showing its structure; (b) Earth's atmosphere; (c) the Earth's crust is not uniform.

Study Fig. 11.13 and answer the following questions.

SAQ 6

a) List the layers of the Earth's body and atmosphere in a sequence starting from its inner core.

b) What is the layer of air that we breathe and the part of the Earth we live on, called?

c) Is the crust of the Earth uniform?

The Earth's **atmosphere** has been studied extensively with the help of ground based experiments, aircraft, rockets and balloons. Though it is not divided into distinct layers, it is helpful to think of the atmosphere in this way. The **troposphere**, nearest to the surface, is made up of 78 per cent nitrogen and 21 per cent oxygen, with water vapour, carbon dioxide, neon and argon making up most of the remaining one per cent. It has an average temperature of about 16°C at sea level and −16°C near its top. The **stratosphere,** coming next contains ozone and has a temperature ranging from −16°C to −4°C. This ozone layer absorbs the harmful UV radiations from the Sun, thus protecting us from them. The carbon dioxide in the Earth's atmosphere traps heat and makes it warmer through the greenhouse effect (recall Sec. 11.4.2). Were it not for this, the Earth's surface temperature would be much lower and it would always be covered with ice.

We will now describe, in brief, the Earth's own structure and composition. Its **crust** is about 10 km thick under the oceans and about 65 km thick under the continents. If you imagined the Earth to be apple sized, its crust would be as thick as the apple's skin. The main elements in the crust are oxygen (47.3 per cent) and silicon (27.7 per cent). Elements such as aluminium, iron, calcium, sodium, potassium and magnesium make up about 23 per cent, with less than 2 per cent being made up of all other elements.

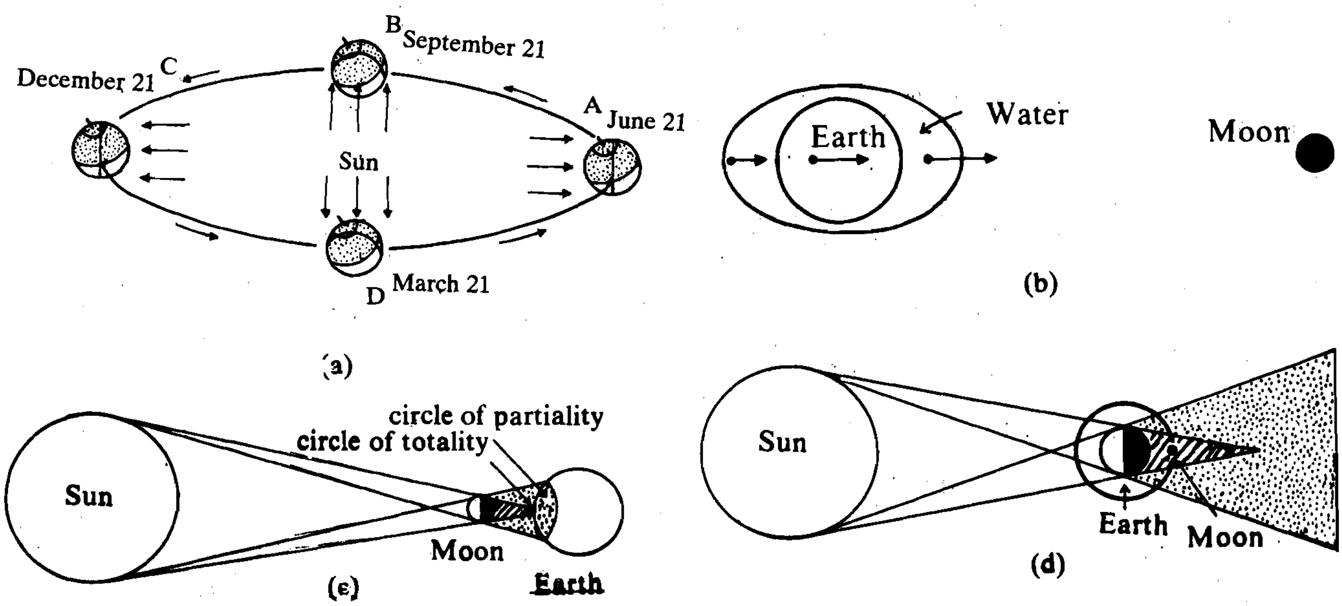


Fig. 11.14: (a) The change of seasons on the Earth results from the tilt of its axis of rotation. For half a year, the north pole leans towards the Sun causing the Sun's rays to strike the northern hemisphere (shaded area) more directly. For the rest of the year the South pole leans towards the Sun and the Southern hemisphere receives stronger sunlight. There would be no seasons on Earth if its axis of rotation were perpendicular to the plane of its orbit; (b) tides on Earth due to Moon's presence; (c) solar eclipse. An observer within the circle of totality will see a total eclipse, while an observer in the circle of partiality will see only a partial eclipse; (d) lunar eclipse.

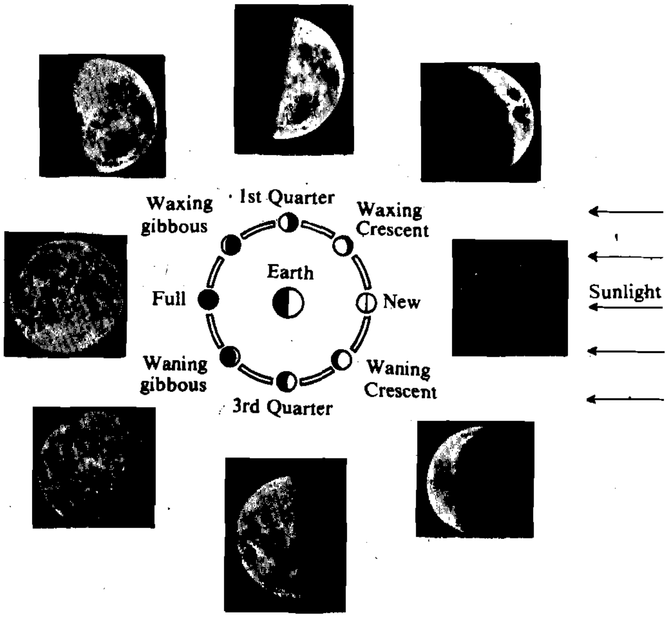
Crust is the topmost part of a layer called **lithosphere,** the Earth's outer layer. The lithosphere has lumps which we see as mountains, and wrinkles in the form of trenches in the ocean. Beneath the crust, the bulk of the Earth's interior is hot and partially molten.

Let us briefly discuss our day-to-day experiences on the Earth, for example, the Earth's rotation on its axis, once every 24 hours, gives it a 24 hours day and night. The regular seasons on the Earth result from the fact, that the Earth's axis of rotation is tilted at an angle to the normal. If it were almost along the normal, like the axes of rotation of some other planets, there would be no seasonal changes on the Earth (Fig. 11.14a). The Earth's rotation on its axis and revolution around the Sun makes it appear as if the Sun, stars and planets were moving in the sky. Then there are phenomena like tides in the sea or ocean, and solar and lunar eclipses (Figs.11.14b,c,d). These are caused by the presence of the Moon, a satellite of the Earth. Let's find out more about the Moon.

The Moon, the Earth's Companion

What do you normally observe about the Moon? It shines brightest, whenever present in the night sky. It seems to go through phases and it seems to present the same side toward the Earth always. Let's first explain these observations. The Moon appears to be the brightest night object, because it is the nearest to the Earth. Its phases occur because of its revolution around the Earth (see Fig. 11.15a). It revolves in an elliptical orbit round the Earth, once in 27.33 days. In the same time, it rotates once on its axis. Thus, we always see the same face of the Moon from the Earth.

The Moon is the only other heavenly body on which human beings have landed. They have spent only a short period, though, a total of only 13 days. They brought back samples of lunar rock and soil and much more information about the Moon which we'll



(a)

(b)

Fig. 11.15: (a) Phases of Moon; (b) far side of the Moon.

briefly describe. The Moon's surface has flat dark expanses called maria (seas), big and small craters, mountains and valleys. It also has rilles, i.e., channels such as the ones made on the Earth by the cutting action of water in a river bed. There are also dome-like structures made of concentric mountain rings.

The Moon rocks and soil are almost similar to the earth rocks and soil. However, they are older and contain much higher levels of some elements like titanium and lack elements like sodium and potassium. The lunar soil has the texture of fine damp sand. Unlike its face, the far side of the Moon has no seas, mountains or valleys (Fig. 11.15b). It has only uniformly distributed craters. The temperature of the Moon ranges from 130°C in areas directly under the Sun, to −170°C on its night side. It has neither water nor any atmosphere. About three billion years ago the Moon's interior cooled. Since then, it has changed very little and has settled down to a quiet existence.

Though the Moon is a dead world, it is of interest to us. Its mysteries are not fully understood yet. It awaits further exploration.

SAQ 7

a) The Moon has a period of revolution of 27.33 days and presents almost the same 'face' toward the Earth at all times.
   Therefore, which of the following is true:
   i) its period of rotation is 29.5 days.
   ii) its period of rotation is 27.33 days.
   iii) it does not rotate.

b) Why is the Moon a dead world?

....

....

....

Having learnt so much about the Solar System, don't you wonder how it was formed, how it came to be what it is? We will now describe the theory that seems to explain best the observations about the Solar System.

11.6 FORMATION OF THE SOLAR SYSTEM

This theory is based on the assumption that the Sun and all the planets were formed from a huge rotating cloud of interstellar gas and dust (see Fig. 11.16). For some reasons, the cloud started contracting. The contraction was hastened by its gravitational

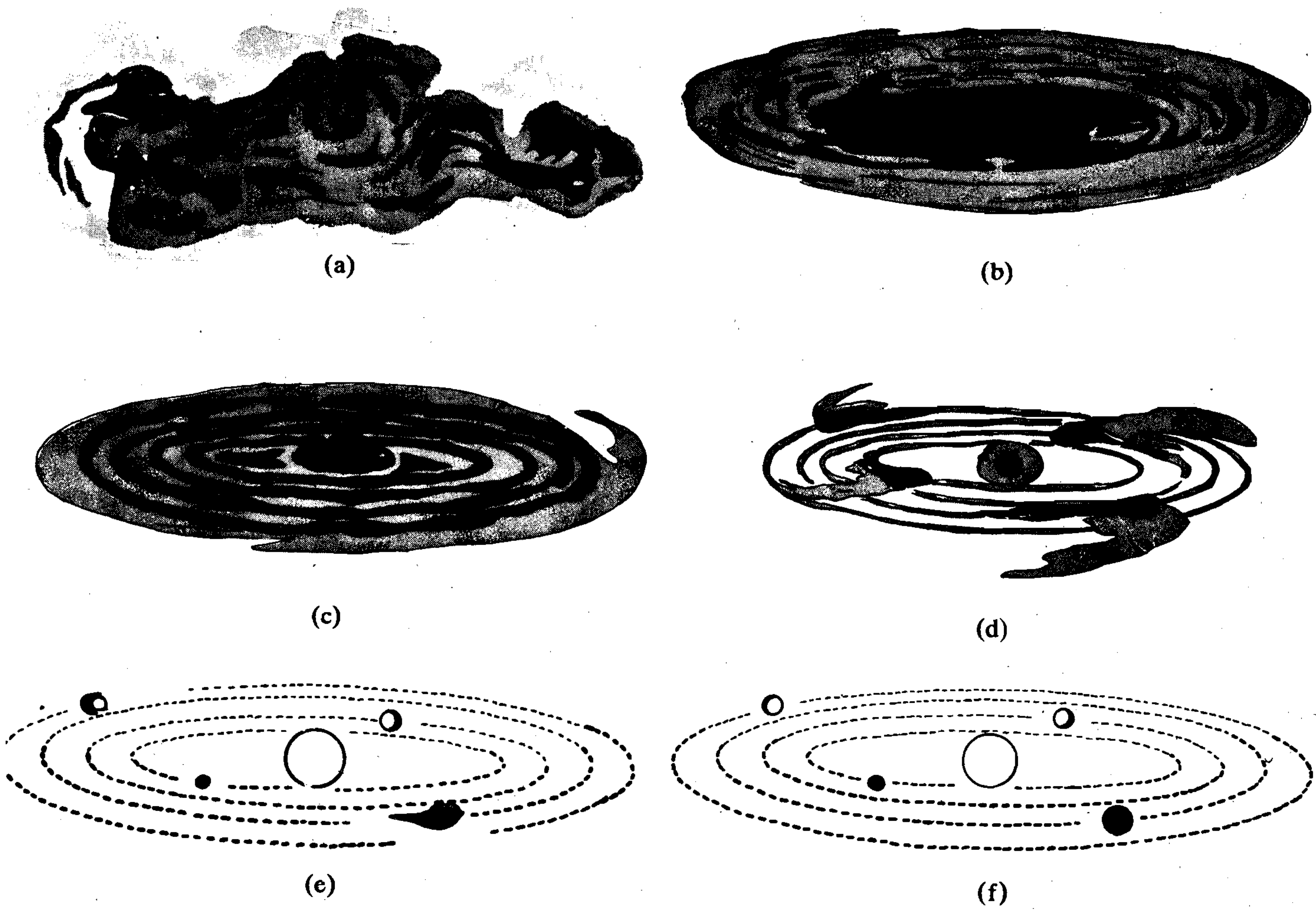


Fig. 11.16: Sketch showing a theory about the formation of Solar System.

pull. The cloud continued to contract (Fig. 11.16a). It also started rotating faster and became disc shaped (Fig. 11.16b). More and more matter contracted towards the centre of the disc, forming the star to be—the new Sun. The temperature of this star rose due to contraction until it started generating its own energy (Fig. 11.16c). Revolving around the Sun was a disc of gas and dust from which the planets condensed (Fig. 11.16d). In this revolving disc, the lighter elements were thrown towards the periphery and heavier elements concentrated inwards. As the Sun's energy increased, the gas shells around the inner planets were driven off and only cores of heavier elements in the cloud remained (Fig. 11.16e). The outer planets were less affected. Finally, the bright star's radiation removed the last of the system's free gases and a mixed array of planets remained (Fig. 11.16f). The smaller, solid ones were near the star and the much larger gaseous ones farther away. The Earth was the third planet.

The Early History of the Earth

The Earth has been evolving and changing ever since its origin, about 4.5 billion years ago. In the first tens of millions of years of the Earth's evolution, the impact of small bodies, gravitation, squeezing together of matter and some other factors heated it. This caused some of its constituents to melt. Iron melted before most of the silicates. Since it was heavier it tended to sink toward the centre, forcing up the lighter silicates towards the surface, just as hot air rises over a stove. As the iron descended, the Earth's surface heaved and huge bubbles formed, with volcanoes exploding through it and lava flowing over large parts of it. There were violent storms too. At last most of the iron reached the centre, where it accumulated as the core. Slowly, the Earth cooled and quietened down. Then, a thin shell of solid rock was formed on its surface. The rock shell accumulated as the initial continents at the top of the lithosphere, like huge rafts. These initial continents drifted about for billions of years. Scientists believe that they formed a supercontinent, which, about 200 million years ago began to drift apart to become the present continents (Fig. 11.17).

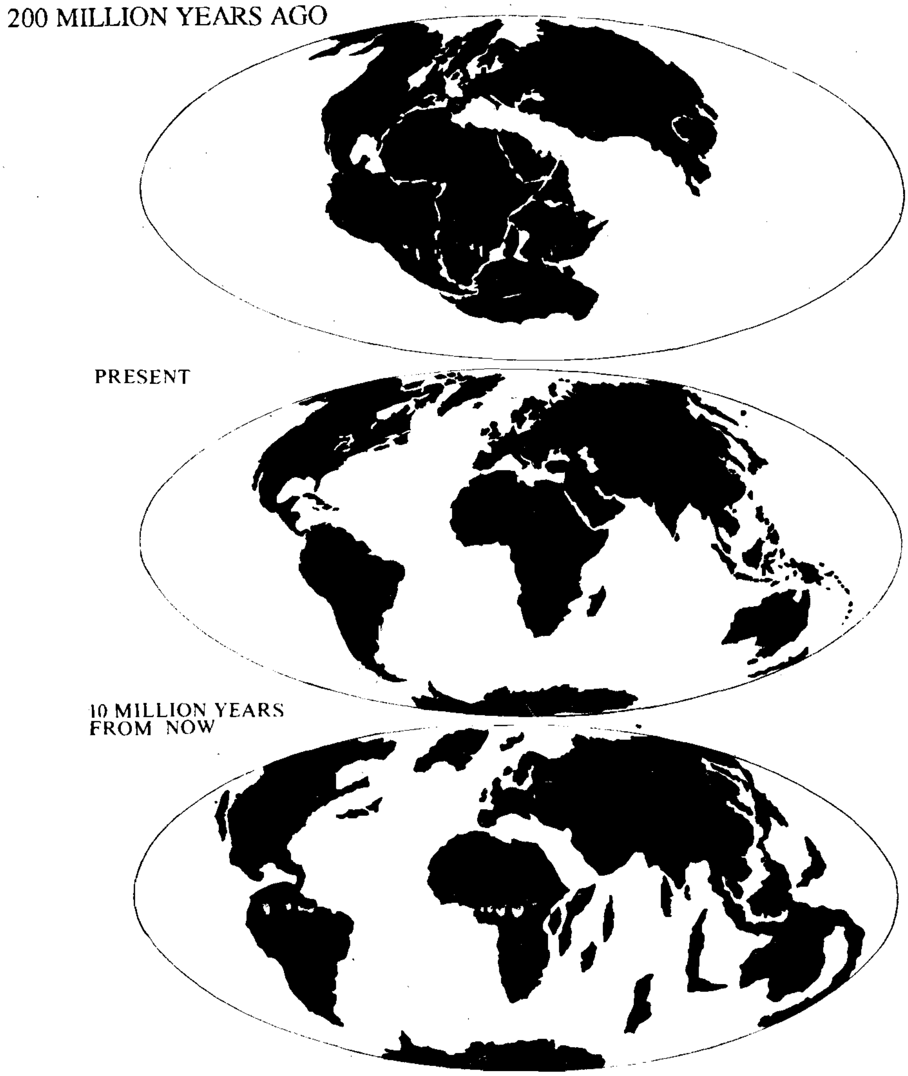


Fig. 11.17: Drift of continents.

An ordinary oxygen molecule has two oxygen atoms in it.

The Sun's radiation had removed the gases from the Earth's surface, so the early Earth had no atmosphere. Water vapour, carbon dioxide, methane and ammonia were released from the molten mass and volcanic eruption and they formed the initial atmosphere. The UV rays from the Sun broke up water into its constituents, hydrogen and oxygen. Being a light gas, hydrogen escaped from the Earth. Oxygen combined with ammonia and methane to form water, nitrogen, carbon dioxide and other compounds. Higher up three atoms of oxygen combined to form ozone molecules and so the ozone layer was formed at the same time. As the Earth cooled further, water vapour in the atmosphere became condensed, and it fell as rain to fill the huge craters on the Earth.

About four billion years ago, a much more remarkable process began on the Earth. This was the first feeble start of life. Paradoxically, the same UV rays that would kill most modern creatures today, helped the beginnings of life. You will read more about this in Unit 12.

The Earth has a special relationship with the Sun. Life on Earth would not have survived, but for the Sun It is a steady source of energy for all basic processes that sustain life. Also the Earth's distance from the Sun is such as to produce a climate that was and still is quite mild, conducive to our kind of life. You will understand this relationship better, once you read Units 12 and 14.

So far we have discussed various features of the Sun, the planets and their satellites, asteroids and comets, and the formation of the Solar System. It is appropriate that we now analyse some myths and misconceptions associated with their influence on our lives.

11.7 SOME MYTHS AND MISCONCEPTIONS

Recall from Units 2 and 9, how our ancestors watched the Sun and the stars, and from their movements predicted the changes in season and the timing of floods. They could also relate the ocean tides to the Moon's apparent changes of shape. There were planets too in the sky. Only five of them could be seen—Mercury, Venus, Mars, Jupiter and Saturn. If the Sun could bring summer and winter, and the Moon move the oceans, why would the planets not have power over earthly affairs?

Out of this wrong, but natural conviction grew astrology. The idea started developing that a person's future was determined by which constellations the planets were in at the moment of his or her birth. The motion of the planets was believed to determine the fates of kings, dynasties and empires. Astrologers studied the motion of planets accurately. They would know what had happened, the last time that, say, Mars was rising in the Constellation of the Lion. Perhaps a similar thing would happen again. And, thus, they would tell kings when to attack a neighbouring state. If the position of the 'war gods' Saturn and Mars were 'unfavourable', they might advise the king to postpone his campaign. A good way to overthrow a regime was to predict its downfall! And if planets could determine the fate of nations, they could also influence the events in a person's life. Thus, astrology grew into a strange combination of observations and mathematics, with illogical thinking. Nevertheless, with time, astrologers came to be patronised by the State. This led to an increase in the influence of astrology, which continues to this day all over the world. But a precise cause and effect relationship between the movements of planets and human beings has never been scientifically established. In fact a critical analysis of astrological beliefs would show you that they re totally unscientific; they can be disproved in the light of the day to day events.

Activity
Compare a few clippings from different newspapers of the same day, which have columns predicting events in the lives of persons belonging to various zodiacal signs.

You will notice that each one says a different thing, in an equally vague manner. You will also find that none of the events occurring in your life in the following week were predicted by any of them with any certainty! Similarly, in our society, many wild beliefs and superstitions are associated with the occurrence of solar eclipses, the appearance of comets, etc. Now that you have some idea about our Solar System, we hope you realise that these notions have no rational basis.

11.8 SUMMARY

- In this unit we have briefly described some of the major characteristics of the Solar System, i.e., the Sun, the planets and their satellites, the asteroids and comets.
- The formation of the Solar System and the early history of the Earth have also been discussed.
- We have tried to analyse how, many of the myths and misconceptions about the influence of planets on human lives arose and show that there is no rational basis of such ideas.

11.9 TERMINAL QUESTIONS

1) List two properties that distinguish the terrestrial planets from the Jovian planets.

....

2) The maximum surface temperature of Venus is greater than that of Mercury even though it is farther away from the Sun. How does this happen?

....

....

3) Why do some comets return frequently near the Sun?

....

....

4) Put the various steps in the formation of Solar System listed below in their proper sequence by numbering them from 1 to 4.
   i) As matter contracted towards the disc's centre, the Sun was born ....
   ii) Gases in the inner planets were driven away leaving them as solid; the outer planets remained gaseous ....
   iii) A huge rotating interstellar gas cloud started contracting and after a while became disc shaped ....
   iv) The planets condensed from the cloud of gas and dust surrounding the Sun .....

5) List three features which distinguish the early Earth from the present day Earth.

....

....

11.10 ANSWERS

Self Assessment Questions

1) The Sun, the nine planets and their satellites, asteroids and comets.
2) a) Hydrogen, helium

b) The hydrogen nuclei fuse together to form helium nuclei giving off energy.
c) About 5 billion years.
d) It will become a white dwarf and eventually a black dwarf.

3) a) The movement of sunspots on the Sun's photosphere.
b) Increase and decrease of sunspots, solar wind, solar flare.

4) a) Because of the clouds on Venus.
b) Its 24-hour day, changing seasons, ice caps on its poles; white clouds and dust storms in its atmosphere.
c) Because they are believed to be chunks of solar material which could not form into a planet, like the rubble of a collapsed building.
d) A meteorite is a heavenly object that strikes the Earth's surface; a meteor is a streak of light produced in the atmosphere when a particle of cosmic dust or any other object from space enters it.

5) a) The size, composition, density and the large number of satellites of Jupiter.
b) Saturn's rings; its average density is less than water.
c) The path of Uranus showed deviations. Because the deviations in the paths of Uranus and Neptune cannot be explained with Pluto's presence alone.
d) Head: water ice mixed with frozen methane, carbon dioxide and ammonia; tail: dust and gas.

6) a) inner core; outercore; mantle, crust; troposphere, stratosphere, upper atmosphere.
b) troposphere, crust
c) No, it has mountains and trenches filled with oceans.

7) a) ii b) It has neither atmosphere nor water to sustain life.

Terminal Questions

1) Composition, density
2) Greenhouse effect. You can explain it.
3) They acquire short period orbits if they pass near a big planet, like Jupiter or Saturn, because of its gravitational pull.
4) i) 2 ii) 4 iii) 1 iv) 3
5) Much higher temperatures and violent conditions, no atmosphere, no life.