# UNIT 9 UNIVERSE AS A SYSTEM

## Structure



## 9.1 INTRODUCTION

In Unit 8 you have studied about the method of science and the nature of scientific knowledge. The scientific method has helped us unravel many mysteries of nature, the origin and evolution of universe being one of them. In the last few thousand years, we have made many discoveries about the universe. But, the most spectacular and unexpected discoveries have been made only recently, in the twentieth century. Modern science has revealed to us a vast and ancient universe.

In this unit we will see how our understanding of the universe has progressed through the ages and what our current perceptions about the universe as a system are. We will briefly describe whatever we now know about the physical universe, that is, the objects that constitute the universe. Our present understanding of the universe has resulted from the powerful and elegant methods placed at our disposal by science. These include the analysis of light, heat and other radiations coming from space, as well as space explorations by various probes and human beings. In Unit 10 we will describe what methods are now used for exploring the universe, and what our current ideas and concepts of the universe are.

### Objectives

After studying this unit you should be able to:

- describe how human understanding of the universe has changed through the ages, from prehistoric to modern times,
- explain the major observations that radically altered the perceptions of the universe prevailing at various times in human history,
- describe the various physical objects that constitute the universe,
- list some features of our galaxy, the Milky Way.

## 9.2 HISTORICAL PERSPECTIVE

You have briefly studied, in Units 2 to 6, what our ancestors' ideas about the heavens were. You know that the primitive human beings depended on food gathering and hunting for their survival. The availability of food depended on the seasons and the seasons depended on the movement of the Sun and stars. Thus, the Sun and the stars controlled the seasons, food and warmth. Similarly, the Moon's motion controlled the tides and the life cycles of many animals. Hence, it was natural that the primitive people noted the rising and setting of the Sun, the reappearance of the crescent moon after the new Moon and the waxing and waning of the Moon. The more accurately they knew the position and movements of the Sun, Moon and stars, the more reliably

Certain stars rise just before or set just after the Sun, at times and positions that vary with the seasons. If one made careful observation of the stars and recorded them over many years, one could predict the seasons. One could also measure the time of year by noting where on the horizon, the sun rose each day. Thus, there lay in the skies a great 'calendar' available to anyone who cared to read it.

they could predict when to hunt, when to gather the tribe and when to move to warmer places. In other words, their survival depended, to a great extent, on their ability to read the 'calendars' in the sky (read the margin remark). The earliest such records are in the form of bone engravings depicting the phases of the Moon. These are estimated to be about 30,000 years old.

However, the primitive people's universe was restricted to only the small patch of land bounded, perhaps, by rivers, distant hills or by the blue line of the sea. Overhead was the sky across which rode the Sun, a god giving light and warmth, and the Moon, a lesser god shining with paler light. With the Moon at night rode innumerable brilliant stars. Outside this little universe lay unimagined mystery.

With the discovery of agriculture came the need for sowing and reaping of crops in the right seasons. As you have read in Unit 2, fairly accurate calendars based on the regular movement of the Sun, Moon and stars were made in Babylon and Egypt long before 2500 B.C. With the passage of time, human thought grew and improved. Between 600 and 400 B.C., a great revolution in human thought began when philosophers in many societies all over the world tried to understand the universe without invoking the intervention of gods. They observed the world around them and looked for rational answers to questions like: Why did the Sun rise at different places? Why did the Moon change its shape? Why did a few stars, later called planets, move among the others? Did such things have any meaning for men? However, with their limited tools of observation and experimentation, their theories about the universe did not, for a long time, progress beyond an earth-centred system. Let us see what the ancient ideas about the universe as a system were.

## 9.2.1 Geocentric Universe of the Ancients

The earliest ideas of the Egyptians and Sumerians about the universe may seem strange to us. The Earth appeared flat and solid to them. The Egyptian cosmos has been depicted in Fig. 2.21 in Unit 2. Similarly, the Sumerians visualised the universe as a flat Earth covered by the heaven made up of tin! Between them lay the glowing Sun, Moon planets and stars which were controlled by the gods. The Earth was obviously the principal thing in the universe. Indeed, they knew no reason to think otherwise. They accepted the Sun, Moon, planets and stars for what they looked like.

**The Earth is Round**

The idea of a flat Earth was discarded by the Greeks. As early as 600 B.C., the philosopher Thales thought the Earth to be round. Pythagoras and his disciples also

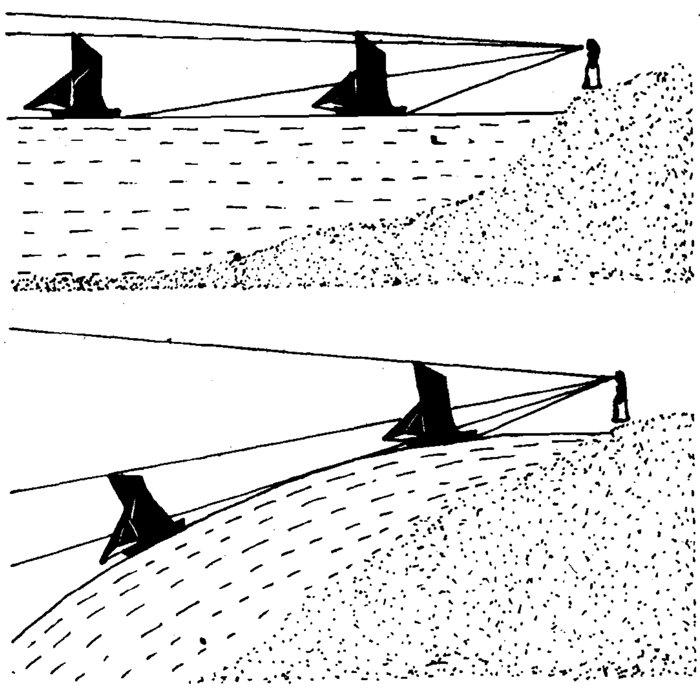



**Fig. 9.1:** The Earth is not flat; (a) if the Earth were flat, a ship would always be seen complete, though fainter as it moved away; (b) actual observations show a departing ship to be sinking as it disappears below the observer's horizon.

maintained that the Earth was spherical. They reasoned that it must be round because of the way ships seemed to sink below the horizon of the sea (Fig. 9.1) or because of the circular shadow it cast on the Moon during an eclipse

**SAQ 1**

Give short answers in the space provided.

a) Of what practical value were astronomical observations of the ancients?

..........................................................................................................................................

b) What observations led Pythagoras and his followers to conclude that the Earth was spherical?

..........................................................................................................................................

The word 'planet' means a wanderer in Greek.

Greek astronomers had also mapped the stars and constellations and had estimated the brightness of the stars. They had observed the apparent motion of the planets which seemed to wander amidst the stars, with some, like Mars, even travelling backwards. The problem before them was to figure out the 'real' motion of the planets as seen from up in the sky, away from the Earth, in such a way that it explained their apparent motion as seen from the Earth. We will now describe the model of the universe figured out by the Greeks.

**The Ptolemaic System**

The theoretical model of the universe given by the Greeks had a stationary Earth at its centre, around which the Sun, the Moon and the planets moved in circular orbits. In this model of the universe, stars merely acted as a backdrop, much like a painted screen hung by a photographer at a village fair! But, doesn't this seem to be the most natural idea in the world? The Earth seems steady, solid, unmoving, while we can see the heavenly bodies rising and setting each day.

Most of the models constructed by the Greeks to explain the movement of planets consisted of perfect concentric spheres or circles. They held that each planet was attached to an invisible sphere or a circle that rotated around the Earth at a different speed from the rest of the spheres. You may recall Eudoxus' model of 27 spheres. shown partly in Fig. 3.12 in Unit 3.

The astronomical ideas of many earlier Greeks were gathered by Ptolemy who published them in his Almagest. This series of thirteen volumes contained the ideas of such men as Aristotle, Apollonius, Hipparchus, in addition to his own ideas. This combined picture of the universe is called the Ptolemaic system (see Fig. 3.14 in Unit 3).

There were some exceptions to this model. Notable among these was the argument of Aristarchus of Samos, that the Earth was one of the several planets, which like them orbits the Sun which was at the centre of the universe. He also argued that the Sun was much bigger than the Earth and stars were enormously far away. However, we do not know how he reached these conclusions, each of which is correct. As you have read in Unit 3, these ideas were rejected under the overwhelming influence of Aristotelian ideas.

In Units 2 to 4, you have also read about the parallel developments in India in the field of astronomy. You know about Aryabhatta, a leading Indian astronomer of the fifth century A.D., who believed in the rotation of the Earth about its axis. He had also given a rational explanation of the occurrence of eclipses. However, his ideas did not survive for long in the prevalent social conditions in India.

**SAQ 2**

Indicate whether the following statements are true (T) or false (F). Write your answers in the space provided.

a) Ptolemy believed that the Sun was stationary..................................
b) In the geocentric model, the Earth was at the centre, the rest of the heavenly bodies moved around it in circular orbits.............................
c) The geocentric model held that the Earth was at centre and stationary, the Sun Moon and the planets moved around it, the stars were fixed in the sky.. ................
d) An exception to the geocentric model given by Aristarchus, was a model with the Sun at the centre.......................

The Ptolemaic model of the geocentric universe held sway for over 1,000 years. With the Renaissance in Europe, scientists took to the path of observation and experiment. The fifteenth century European astronomers built observatories, improved Ptolemy's instruments and devised novel ones. As was bound to happen, their observations began to clash with Ptolemaic theory. As the observations about the paths of the planets became more accurate, Ptolemy's model was increasingly strained to fit the facts.

The Renaissance had opened the vast storehouse of ancient Greek knowledge to European astronomers. A Polish astronomer, Nicholas Copernicus, re-examined the long neglected sun-centred theories of the universe. In 1543, he published quite a different hypothesis, from the prevailing Ptolemaic model, to explain the apparent motion of planets. Its most daring feature was the proposition that the Sun, not the Earth, was at the centre of the universe.

## 9.2.2 The Copernican Revolution

The Copernican model consisted of the Sun at the centre with the six planets, Mercury, Venus, the Earth with the Moon-round it, Mars, Jupiter and Saturn going round it in circular orbits. In this model too the stars formed a fixed sphere in the background (see Fig. 9.2). Copernicus also believed all planets to be of the same size. His model worked as well as Ptolemy's spheres in explaining the apparent motion of the planets. But it led to a confrontation with the adherents of geocentric model. It was not generally accepted until much later when Galileo's and Kepler's works proved that the heliocentric model was valid.

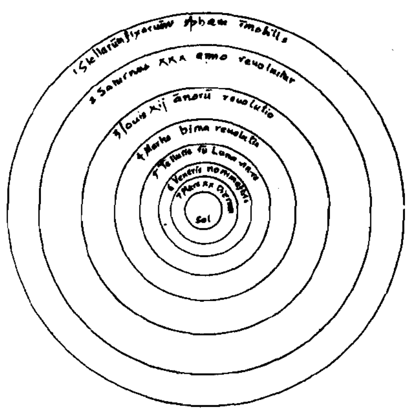



**Fig. 9.2:** Copernican system

The sun-centred model of Copernicus was established by the astronomical observations of Galileo Galilei when in 1609, he turned his small, imperfect telescope towards the sky. In the first few nights of observation of the heavens, Galileo saw enough to shatter the ancient picture of the serene, perfect, harmonious world.

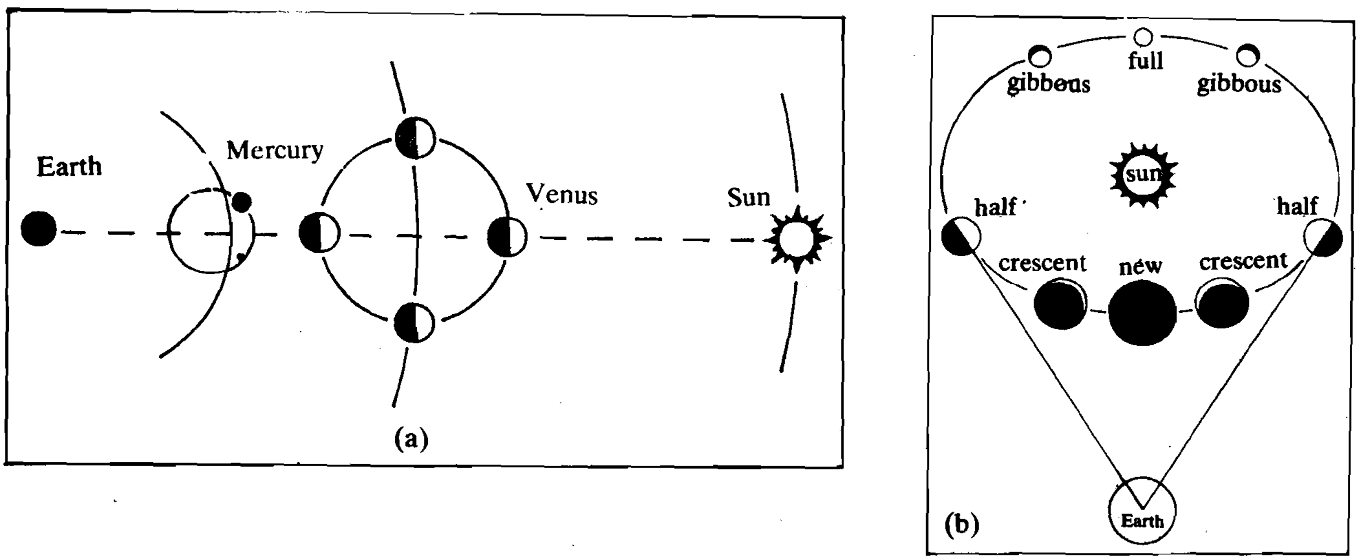



**Fig. 9.3:** (a) The phases of Venus cannot be explained by Ptolemaic model; (b) phases of Venus in Copernican model.

For, the Moon, instead of being a perfect, smooth sphere, was found to be uneven, covered by mountains and deep depressions; the planet Saturn seemed divided into three. He also saw four Moons circling around the planet Jupiter. Hence in the heavens was a small scale model of the Copernican system. The planet Venus showed phases like the Moon. The fact that the Venus showed a fully lighted phase when it was near the Sun could not be explained by the Ptolemaic system. Only the Copernican model which allowed Venus to circle around the far side of the Sun from the Earth, could explain it (see Fig.9.3).

In spite of the prevailing opposition to Copernican model, these observations were eventually accepted and they led to the final overthrow of the geocentric model. Interestingly, the earth-centred ideas remain with us in our everyday lives even now. It is almost 2,200 years since Aristarchus and almost 400 years since Galileo, but our language still 'pretends' that the Earth does not rotate. For instance, we still talk about the Sun 'rising' and the Sun 'setting'!

**SAQ 3**

a) The Copernican model was not able to explain the planetary motion much better than the Ptolemaic model. Why then, was it accepted in spite of the initial general opposition? Write your answer in the space given below.

..........................................................................................................................................

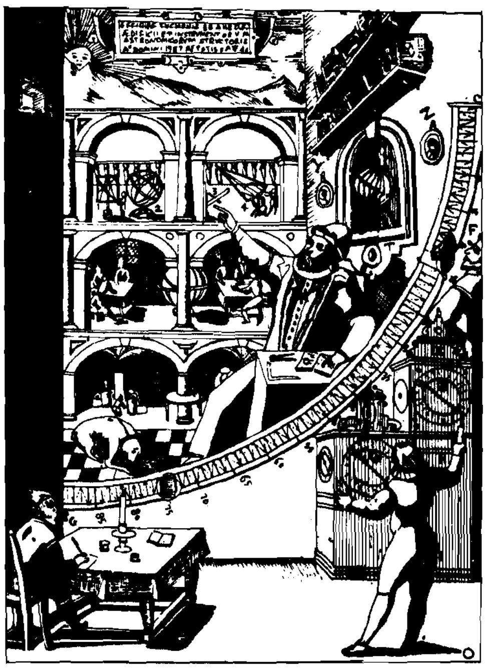
b) Which two among the following observations provided conclusive evidence in support of Copernican model? Tick (✓) the appropriate choice in the boxes provided.

   i) The sun rises in the east and sets in the west. ☐
   ii) The planet Venus shows phases like the Moon. ☐
   iii) The planet Saturn seemed divided into three. ☐
   iv) Four moons can be seen moving around the planet Jupiter. ☐

**Kepler's Laws of Planetary Motion**

Further support to the heliocentric model came from the work of Johannes Kepler at around the same time as Galileo's observations. Kepler, a German astronomer, was

(a)

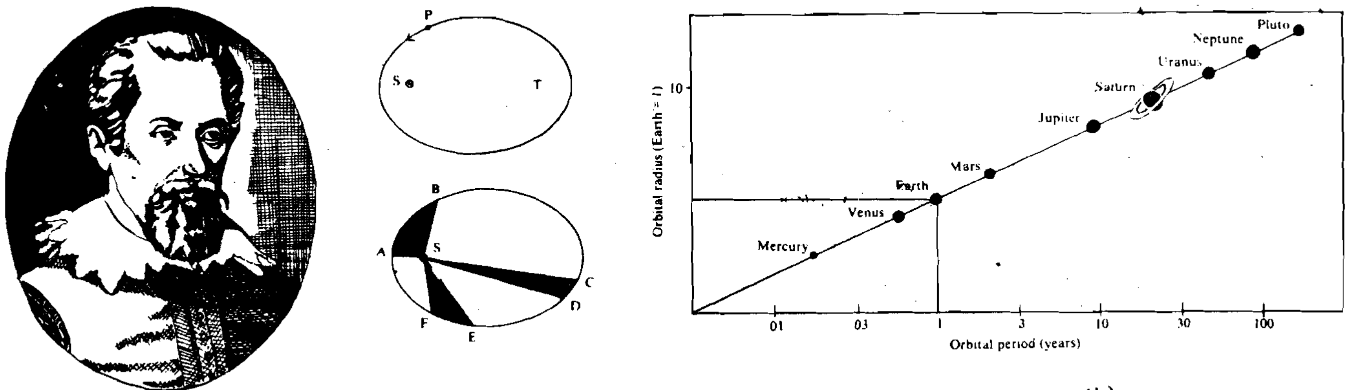


(b)

**Fig. 9.4** (a) Tycho Brahe; (b) Brahe's observatory at Uraniborg in Denmark. Note the huge brass quadrant arc.

trying to work out a theoretical model which explained all observations of planetary motion. The most accurate observations of apparent planetary positions had been made by Tycho Brahe (Fig. 9.4).

Brahe invited Kepler to work with him. He recommended that Kepler study the planet Mars because its motion seemed most anomalous, most difficult to reconcile with an orbit made of circles. Further, planets in circular orbits ought to move with constant speed. But Kepler found that their speeds changed with their distance from the Sun. After years of trial and error, he found that the only explanation of the observed movement of Mars was that its orbit was an ellipse with the Sun at one of its foci (Fig. 9.5b). Thus, the idea of circular orbits was abandoned. Kepler eventually succeeded in explaining Brahe's observations which could all be expressed simply, in the form of three laws of planetary motion (see Fig. 9.5). You have read about them in Sec. 8.3.4.




(b)

(a)

**Fig. 9.5:** (a) Johannes Kepler; (b) Kepler's laws of planetary motion.

Kepler's laws removed the main objection of the Copernican model, that this model could not give an accurate description of the observed path of the planets. These laws also led to the rejection of Pythagorean-Platonic view of the heavens showing only perfect circular motions, which even Copernicus had retained. By the end of the seventeenth century the heliocentric model of the universe came to be accepted generally. Interestingly, the physical proof of the movement of the Earth came when it was no longer necessary, because by then everybody had already accepted that the Earth moved around the Sun. Let us see what it was.

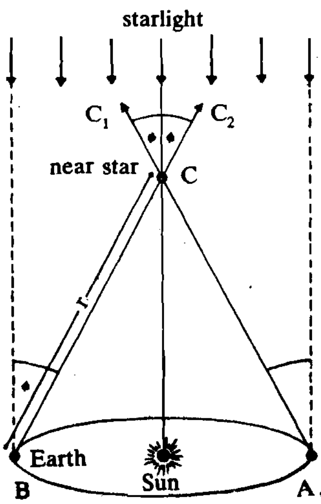



**Fig. 9.6:** Stellar parallax, the method for determining the distance to a 'near' star. The distance r is related to the angle $\phi$ by a simple formula

$$r = \frac{3.26}{\phi} \text{ light years}$$

The angle $\phi$ is measured in seconds of an arc. One second of an arc is equal to $\frac{1}{3600}$ degree.

### Stellar Parallax

Study Fig. 9.6. If the Earth were stationary, a given line joining point A on the Earth, a nearby star C and any given distant star would never vary. However, if the Earth changed its position in space and moved from A to B, this alignment would also change. Thus, in the background of more distant stars, the nearby star would appear to shift from $C_1$ to $C_2$ as the Earth moved from A to B. This apparent shifting of nearby stars against the background of more distant ones has been observed, and the phenomenon is called **stellar parallax**. It is a periodic kind of a change. A given star first shifts one way and then the other, during the course of one year, hence it must be due to the fact that the Earth is moving around the Sun.

The change is small, less than a second of an arc. It was only in 1838 that Friedrich Bessel, a German astronomer, could measure the stellar parallax of a star. The nearest star, the Sun when viewed against distant stars appears to shift approximately 1° per day.

### SAQ 4

Give short answers in the space provided

a) What is the shape of the planetary orbits? .............................

b) Express Kepler's second and third laws in common language. (*Hint:* see Unit 8).

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..............................................................................................................................

c) What observation shows that the Earth moves round the Sun? ..................................

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**Stars in the Limelight**

Among Galileo's many discoveries with the telescope was his observation that the white nebulous band in the sky known as the Milky Way (*Akash Ganga*) was in fact made up of very many stars. Till this time, the model of the universe had consisted merely of the then known Solar System, with stars being nothing more than point sources of light. With the availability of bigger and better telescopes in the post-Galilean era, the remaining planets of the Solar System, Uranus, Neptune and Pluto were discovered and the stars came to be examined in greater detail.

The Milky Way was named so because it looked like a trail of milk spilled in the sky. Our culture called it Akash Ganga, i.e., the river Ganga in the heavens. What fertile imagination our ancestors had!

The first ever study of the stars was made by the English astronomer William Herschel (1738-1822), who had earlier discovered the planet Uranus. Herschel showed in 1785 that the stars were not the backdrop to the Solar System but were individual objects that extended to infinity. He prepared the first ever map of the Milky Way Galaxy and showed that it was, in fact, a part of a flat disc of countless stars. In his model, the Solar System was situated within the Milky Way Galaxy which constituted the whole Universe. At that time, the telescopes were not very powerful. One could see in the sky, point-like objects, the stars. One could also see white fuzzy clouds called nebulae.

The term nebulae is now used for glowing clouds of gas and dust in a galaxy. A galaxy is made up of gas, dust and stars. Galaxies are islands of stars scattered in the vast space, like islands in an endless ocean or oases in a boundless desert. The white band seen in the sky and called the Milky Way, is only a part of the Milky Way Galaxy

When we entered the twentieth century, the model of the universe was still heliocentric. Our Sun was at the centre of the Milky Way Galaxy which with its stars and nebulae was the whole of the universe. However, it did not take long for the heliocentric model to be abandoned. We will now describe, in brief, the observations that led to the rejection of heliocentric model.

## 9.2.3 Rejection of Heliocentrism

This happened in the year 1918 when the astronomer Harlow Shapley (1885-1972) first surveyed the size and shape of the Milky Way Galaxy. He showed, by his most original researches, that the Sun does not lie at the centre of the Milky Way Galaxy, but is located a great distance away from the centre. But the question whether the Milky Way Galaxy was the whole of the universe or not, still remained. The answer came in the year 1924, when Edwin Hubble (1889-1953), another great astronomer, showed that the fuzzy cloud called Andromeda nebula was not a member of the Milky Way Galaxy. In fact it was a separate galaxy. Soon, other galaxies were spotted, but the Milky Way Galaxy appeared to be the largest. This was some consolation to the human ego: if the centre of the universe was neither reserved for our Earth, nor for our Sun, at least we lived within the largest galaxy. This idea also did not last long. Walter Baade (1893-1959) turned the telescope on many cosmic details that Hubble had skipped over. He discovered that the other galaxies were farther away than we had supposed, and the Milky Way Galaxy was no bigger than the others. It was merely one galaxy among countless others.

The revolution that had begun with Copernicus was now complete. We had no special place in this universe! We were not at its centre. In fact, the universe was found to have no centre and not even a boundary. Indeed, the greatness of Copernican ideas lies not so much in what Copernicus did as what his work led to.

**SAQ 5**

The following statements about the way human perception of the universe has changed through the ages, are arranged randomly. Put them in a chronological order by placing the numbers 1 to 7 against the appropriate statements.

a) The Sun is not at the centre of the Milky Way Galaxy which is still the whole of the universe..............................
b) The Universe is without any centre or boundary, the Milky Way Galaxy is one among the countless galaxies in the Universe..............................
c) The Earth is flat and solid, with the sky on top and the Sun, Moon and stars in the middle..............................
d) The Sun is at the centre of the universe and the planets move around it in circular orbits..............................

e) Other galaxies are there in the universe, but the Milky Way Galaxy is at the centre. ................................

f) The Earth is spherical. It is at the centre of the universe. It does not move. ................................

g) The planets move around the Sun in elliptical orbits according to certain laws but the sun is at the centre of the universe................................

So far we have given a brief description of how human perception of the universe has undergone a change in the light of more accurate observations in the last four centuries. We will now present our current perception of the universe as a system, of its physical structure. We will describe the varied forms in which matter is distributed in the universe, such as planets, stars, galaxies etc.

## 9.3 THE PHYSICAL UNIVERSE

The universe is vast. The Earth we live on appears to be just a speck of dust circling a small star in a remote corner of an obscure galaxy. If we are a speck in the immense space, we also occupy only an instant in the expanse of time. The universe is also very old. We now know that it is about fifteen or twenty billion years old, while we, the human beings have been around for only two million years or so. This vast and ancient universe is populated with a variety of objects. Let us now understand what objects constitute the universe and how they are distributed. In other words, what the physical structure of the universe is. In doing so, we will not go into its chemical composition or any other details. However, before we embark on this venture, we will give you an idea of the cosmic distances, so that you're able to appreciate what follows.

### 9.3.1 Cosmic Distances

If we asked you what the distance between Delhi and Kanyakumari is, you would say that it is roughly 3000 km. Another way of answering the question would be that a train takes about 50 hours to cover the distance. And if we know the average speed of a train, we would get a fairly good idea of the distance.

$$\text{Speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

The unit used to measure speed is kilometres per second written as km/s.

The dimensions of the universe are so large that using familiar units of distance like kilometres would make little sense. Therefore, cosmic distances are measured in "light years". **One light year is the distance travelled by light in one year.** Now, light travels about 300,000 kilometres in one second, i.e. its speed is $3\times10^5$ kms. At this speed it can travel seven times around the Earth in one second. A year has about $3\times10^7$ seconds (i.e. about 30 million seconds) in it. Therefore, the distance light travels in one year is about

The accurate value of one light year is $9.46 \times 10^{12}$ km. It is calculated by putting in the accurate values of the speed of light, and the number of seconds in a year.

$3\times10^5$ km/s $\times$ $3\times10^7$s$=9\times10^{12}$ km, i.e. about nine trillion kilometres.

This unit of length is called a light year, It measures not time but distances, enormous distances. Space and time are interwoven. We cannot look out into space without looking back into time. If we see a galaxy a billion light years away, we are seeing it the way it was a billion years ago. Thus, the distance in units of light years also tells us how far back into time we are looking.

### 9.3.2 The Solar Family

Let us now take you on a journey across the universe. We begin from our planet Earth. It is our home. The Earth is active, lush and fertile. It is a place of blue skies, vast oceans, cool forests, a world full of life. Its surface is cloaked by an atmosphere in which we can breathe, and which keeps the Earth's temperature quite constant. It spins or rotates on its axis and revolves around the Sun, completing one orbit in one year. The Earth is not alone. It has a companion on its travels, the Moon which orbits the Earth once in 27.33 days. But the Moon is airless, waterless and lifeless; it is a dead world. From the Moon, the Earth appears as a beautiful bluish-white planet.

The term spinning or rotation refers to a body's turning on its own axis, like a spinning top. The term revolution of a body is used to refer to its motion around another body. The Earth rotates on its axis once every 24 hours, and revolves around the Sun once in $365\frac{1}{4}$ days.

The Earth is not the only planet orbiting the Sun. There are eight other planets that orbit the Sun. The nine planets and their satellites together with the Sun and many asteroids and comets make a family, the Solar System (see Fig. 11.1) The planets are diverse in size, ranging from the giant Jupiter, eleven times the size of Earth, down to tiny Pluto, less than half the size of our planet. Each planet's distance from the Sun is different, Mercury being the nearest and Pluto, the farthest. They are all different from each other in many respects. But let's not dwell on the Solar System for long as we will take a closer look at it in Unit 11. Let's see what the space beyond contains.

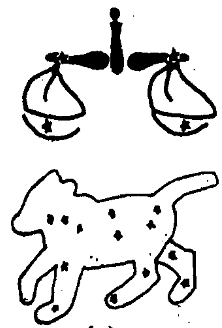
## 9.3.3 The Night Sky

When you look up at the sky on a clear night, what do you see? Most of it is dotted with twinkling stars. You may see the moon or Venus as a bright point or Mars as a reddish one. Venus is sometimes seen in the evening just after sunset and, at other times, in the morning before sunrise. Except for the planets, all other points of light are stars. From our planet Earth, on a really clear, dark night, we can see about 6,000 stars.

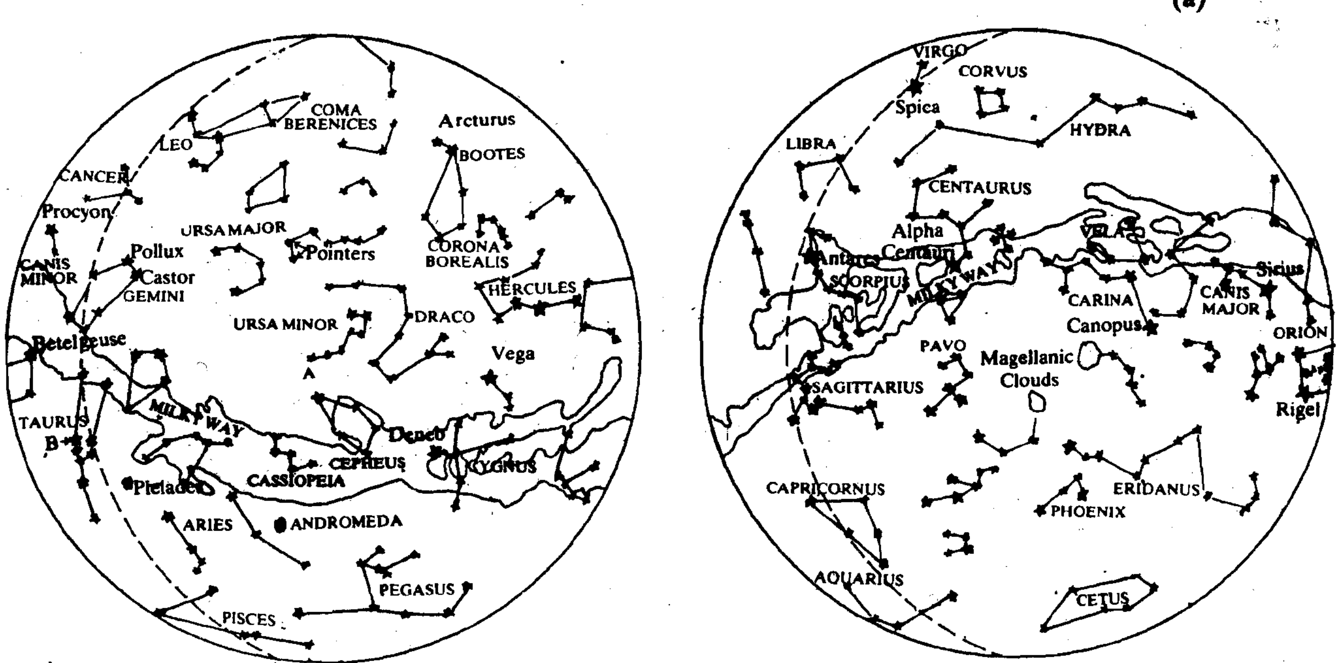
**Stars and Constellations**

The night sky is interesting. The stars seem to fall into certain patterns. You must have seen the Saptarishi, also known as the Big Dipper or the Plough. It is a part of a bigger group of stars called the Great Bear or the Ursa Major which is seen in the northern sky. We can see many different star patterns like the Hunters, the Lion, the Dog, the Balance etc. These pictures are not there really in the sky. Our imagination has put them there. The early star gazers and the ancient astronomers traced out these star patterns and named them after gods and heroes, objects or creatures which these groups of stars resembled in their imagination (see Fig. 9.7a).

The sky is divided into these patterns of stars or star groups which are called **constellations.** A constellation is an arbitrary grouping of stars and it merely defines an area of the sky. All cosmic objects in a given region of the sky form a constellation. There are eighty eight constellations each having a definite boundary. Modern astronomers use the ancient names of the constellations to refer to these eighty eight regions of the sky, and not to the imaginary figures of long ago. In Fig. 9.7 we show the star charts of bright stars and constellations visible in the Northern and Southern hemispheres. You could also look up the star charts published in many newspapers and magazines from time to time and familiarise yourself with the stars and constellations in the night sky.



(a)




(b) (c)

**Figure. 9.7:** (a) Constellations Libra (the balance), Ursa Major (Great Bear); (b) Charts of major constellations and stars as viewed from Northern and (c) Southern hemispheres.

The stars and constellations help explorers and navigators. In the ancient times, they helped the seagoing ships. By watching the position of the constellation with respect to the horizon night after night, the early sailors could determine the ship's latitude. And now the spacefaring ships find their bearings in space with the help of stars and constellations. If we extend the line joining the last two stars of the Saptarishi called the Pointers, we can see the Pole star. It is a bright star situated in the North, almost on the

Earth's axis of rotation. Therefore, it appears like a fixed star. Its position gives the geographical north. Thus, the Pole star also helped the earliest navigators in finding their way at night.

As the Earth revolves around the Sun, different constellations appear, disappear and reappear at different times of the year. Thus, there are different constellations in different seasons. The motion of planets, when viewed against these constellations, appears as if the planets were entering or leaving a constellation at a specific time of the year. Such movements of planets and stars have also been put to 'use' in astrology to predict events in human lives! But, we'll say something more on this in Unit 11.

**SAQ 6**

a) Identify the group of stars called Saptarishi, in Fig 9.9b.
b) Which of the stars marked A and B in Fig. 9.9b, is the Pole star?

On the clear nights you must also have seen a glorious white band stretched across the sky. This is the Milky Way or *Akashganga* which, as you have read in Sec. 9.2.2, was seen by Galileo to have many stars in it. It is a part of our galaxy, the Milky Way Galaxy. Often we simply call it the Galaxy. A galaxy is an enormous collection of gas, dust and billions upon billions of stars. There are millions of such galaxies in the sky. The Solar System and all the stars that we see in the sky belong to the Milky Way Galaxy. Let's now find out more about the Milky Way Galaxy.

### 9.3.4 The Milky Way Galaxy

The white band stretched across the night sky is, in fact, a partial view of the Milky Way Galaxy. Being inside the Galaxy, we can see it only in parts. We cannot see the whole of it, the way we see the other galaxies. Visualising the whole Milky Way Galaxy and determining its shape has not been easy. By watching a large number of galaxies distributed in all directions in dozens of views as far as modern telescopes can see, scientists have been able to form a picture of what our galaxy must look like from outside. In this, they have also been helped by the observations about the stars in our galaxy, their distances and motion, etc. The picture of the Galaxy constructed by the astronomers is shown in Fig. 9.8. Doesn't it look somewhat like a disc or a gramophone record with a swollen centre? The Milky Way Galaxy contains about 100 billion stars. The stars are not uniformly distributed. You can test this yourself by a simple activity.

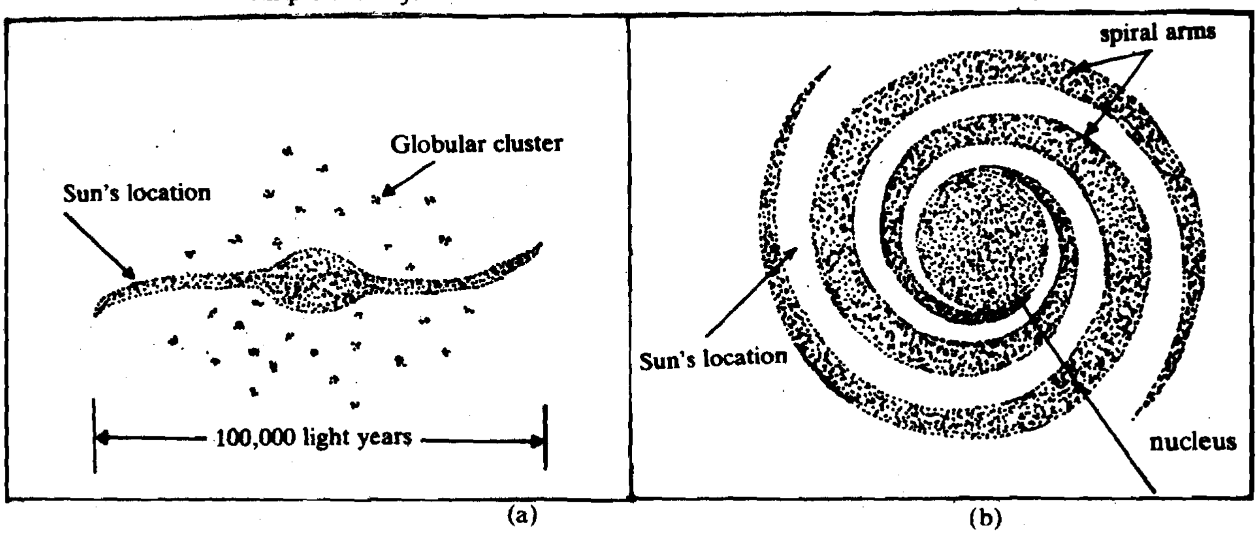



**Figure. 9.8:** The Milky Way Galaxy; (a) edge-on view (b) face-on view.

**Activity**

Cut out a small cardboard frame with a square opening of side 5 cm. Hold the frame at an arm's length and count the stars that you see within the frame. Repeat this for different parts of the sky. Record the location and number of stars counted on each occasion. Are they the same?

You will find that the distribution of stars is not uniform. There is higher concentration of stars in certain parts of the sky. There is a great concentration of stars towards the centre of the Galaxy, which is located in the constellation of Sagittarius. The Sun is situated on its remote outskirts, about 30,000 light years away from the centre. Note that when you see the portion of the Milky Way in the sky near Sagittarius, you would be looking toward the centre of the galaxy. When you observe the portion near Orion, you would be seeing the "edge" of the Galaxy, nearest the Sun. The Galaxy, as you can see in Fig. 9.8, is disc shaped. If we could see our galaxy from the top, we would get the face-on view (Fig. 9.8b). If we could see it from the edge, we would get the edge-on view (Fig. 9.8a).

In the edge-on view, the Galaxy consists of two basic parts: the disc and the halo. The disc consists of stars, as well as clouds of gas and dust called **nebulae**. It has a diameter of 100,000 light years, and a thickness of about 5,000 light years. This collection of gas and stars rotates about the centre (also known as the nucleus) of the Galaxy, with each part moving at a different speed. The Solar System at a distance of about 30,000 light years from the centre, in the outskirts of the Galaxy, also revolves. Moving at a speed of 250 km. per sec., it takes roughly 200 million years to complete one revolution around the centre of the Galaxy. There are individual stars like the Sun as well as groups of stars, called **galactic clusters,** that move together in the disc. Astronomers have identified about 1000 galactic clusters in the disc, each containing 10 to 1,000 stars.

The disc of the galaxy contains spiral arms, which are about 2,500 light years wide. The distance between the adjacent arms is about 1,500 light years. The spiral arms are seen clearly because that is where the brightest stars and gas clouds are found. Dark clouds of dust and gas line the inner rims of the arms. The other stars in the disc are not arranged in any conspicuous pattern. The Sun, for instance, lies between two spiral arms (see Fig. 9.8b).

The halo is spherical and has its centre at the nucleus of the Galaxy. The central region of the halo consists of a vast concentration of stars that form the nuclear bulge of the disc (Fig. 9.8a). Elsewhere the halo consists of very little gas and widely separated stars and about 120 **globular clusters**. The globular clusters are compact spherical systems each containing any number of stars from ten thousand to several millions. It is observed that the halo, or the spherical component of the Galaxy, does not rotate with the disc.

From a study of the distribution of globular clusters, we may conclude that the Sun cannot be at the centre of the Galaxy. Because if it were so, the globular clusters would have been distributed around the Sun. They are not, and hence we may surmise that the Sun is not at the centre of the Milky Way Galaxy. The centre of the Galaxy is, in fact, the centre of the distribution of these globular clusters.

**SAQ 7**

a) Fill up the blank spaces in the following statements about the Milky Way Galaxy.

i) A galaxy is a collection of.............................. The Milky Way Galaxy is one among..............................of galaxies in the universe.
ii) In the face-on view of the Galaxy, we would see it from.............................., viewing it from the edge, we get an..............................
iii) Seen from the edge, the Galaxy seems to be made of two parts:..............................and..............................
iv) The disc is made up of clouds of gas and dust, individual stars and..............................that rotate around the centre of the galaxy. The disc of the galaxy also contains two..............................arranged in a spiral. The sun is situated..............................the spiral arms.
v) The halo is shaped like a..............................In its centre, there is a..............................concentration of stars. Elsewhere, it is made up of .............................. and ..............................
vi) A..............................cluster has about 10 to 1000 stars. A.............................. cluster is made up of 10,000 to millions of stars.
vii) The globular clusters are found in the..............................and the galactic clusters in the..............................of the galaxy.

b) Taking 10,000 light years to be 1 cm on scale, draw the Milky Way in an edge-on view; the diameter of the disc would be 10cm. Show its disc and nucleus. Locate the Sun on this diagram.

### 9.3.5 Beyond the Milky Way Galaxy

Let us now move away from the Earth and venture into the space beyond. If we were at a point far out in space we would see scattered in space, a large number of faint, wispy tendrils of light. These are all galaxies. As we have said earlier in Sec. 9.3.3, these galaxies are made up of billions of stars, and clouds of gas and dust. The universe is full of galaxies. Some of them are solitary wanderers. Most of them move in clusters. drifting endlessly in the great cosmic dark.

#### Shapes of galaxies

The galaxies are usually found in three shapes: spiral galaxies, elliptical galaxies and irregular galaxies (see Fig. 9.9). Further refinements have been suggested in recent years, but we will not go into those details. The **elliptical galaxies** are so called because they have an elliptical shape on a photographic plate. Elliptical galaxies in general do not have much gas or dust from which to form new stars, and they consist of old stars. The **irregular galaxies** do not show any coherent structure. The number of elliptical and spiral galaxies is almost equal, whereas the irregular ones comprise about 10% of all galaxies.

(a) (b) (c) (d)

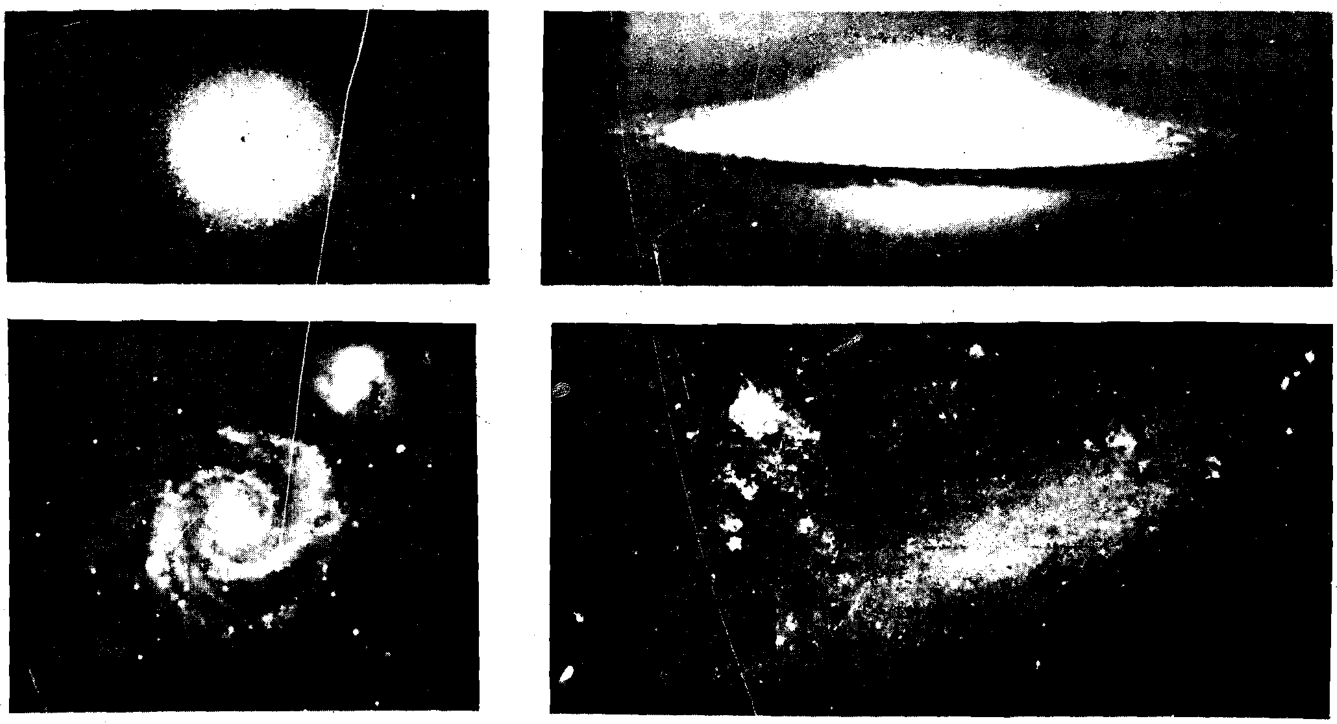


Fig. 9.9: Galaxies of various shapes: (a) the galaxy M 87 at the centre of the Virgo cluster has a mass of 300 billion suns, and is the most massive galaxy known: (b) edge-on view of the spiral Sombrero galaxy; (c) spiral galaxy, face-on view; (d) irregular galaxy, Large Magellanic Cloud.

Before going too deep into the space, let's take a closer look at, what astronomers on Earth like to call, the **Local Group of Galaxies**. Its cross-section is several million light years, it is made up of around twenty galaxies. The nearest galaxies to the Milky Way Galaxy are the Large and Small Magellanic Clouds, visible in the Southern hemisphere. They are irregular in shape. The galaxy Andromeda lies nearly two million light years away and is visible to the unaided eye. It is a spiral galaxy, three times bigger and brighter than ours.

As we move further out, we find that such groupings, or **clusters of galaxies,** are extremely common. There are some hundreds of billions of galaxies in the universe which form clusters of all kinds. There are **rich clusters** containing as many as ten thousand galaxies and **poor clusters** having only a few galaxies. Our own galaxy is a member of a poor cluster. The nearest rich cluster, at a distance of about 70 million light years, is Virgo. It is irregular in shape and is huge, extending 7 million light years from end to end. Like galaxies, clusters are also shaped like spirals, ellipses or they may be irregular.

In recent years, one more step has been added in understanding this physical structure of the universe. There is evidence to suggest that the clusters of galaxies, rich and poor, in turn form superclusters or supergalaxies (i.e. clusters of clusters) that are 200-300 million light years in diameter. They may be made up of about a 100 member clusters. The clusters, Local Group and Virgo, are members of the same supercluster. The superclusters are very much alike. They are rather evenly distributed in space. Thus, on a larger scale than this, the universe appears uniform, that is, it has the same structure and composition everywhere, it looks the same in all directions.

The structure of the universe that we have described above is not static. It is changing. New stars and new galaxies are being born. Stars, galaxies and clusters move. Sometimes they collide giving rise to new galaxies. All these stars, galaxies, clusters and superclusters have a story to tell about ancient events on the largest possible scale. We are only now beginning to read this story.

**SAQ 8**

a) Think of the universe as a system and our planet as its smallest subsystem. Then rearrange the following elements in such a way that shows each successive entity as containing the previous one. List, against each entity, the objects that constitute it.
   i) Earth
   ii) Milky Way Galaxy
   iii) Superclusters
   iv) Solar System
   v) Clusters/Local Group of Galaxies

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b) In the pictures of galaxies given below, identify the shape of each of them.

(i) (ii) (iii)

..............................................................................................................

Before we end this journey, let us show you what the space between the stars and galaxies is made up of.

An atom is the smallest particle of an element. It is made up of a nucleus containing protons and neutrons, and electrons revolving around it. See Fig. 8.4b in Unit 8. A molecule is made up of two or more atoms.

**Interstellar and Intergalactic Space**

The space between the stars and the galaxies looks empty, doesn't it? But this is not true. In the great dark between stars in the galaxies, and galaxies in the clusters, there are clouds of gas and dust. The gas clouds are mainly made up of hydrogen atoms and cannot be seen by the unaided eye. Only the modern astronomical instruments have been able to detect these particles. Cosmic dust is made up of bigger particles. These clouds of dust are revealed when they reflect the light of stars falling on them (Fig. 9.10). Cosmic dust and clouds of gas in a galaxy are found to play a great role in the formation of a star. You will read about this in Unit 10.

(a)

(b)

**Fig. 9.10:** (a) Orion nebula; (b) Crab nebula, remnant of a supernova explosion seen in 1054 A.D.

In the gas clouds and cosmic dust we also find traces of different kinds of ordinary molecules, like water, ammonia, carbon monoxide etc. There are many organic molecules, like methane, methanol (also known as wood alcohol), formic acid (the substance that gives ant and bee bites their sting), and many more. The organic molecules are the matter out of which our kind of life arose on the planet Earth. The abundance of such organic molecules in the interstellar space suggests that there might be life somewhere out there, perhaps in a different form. We may not be the only ones, after all!

Organic molecules are those molecules which essentially contain carbon and hydrogen atoms. They may or may not have other atoms like nitrogen, oxygen etc.

Another major constituent of the universe are cosmic rays. Cosmic rays are beams of charged particles, such as the electrons, protons and helium nuclei etc., that freely travel in space at nearly the speed of light. These particles carry large amounts of energy across space.

Let us now end our brief journey of the universe, and summarise what we have discovered. The matter of the universe is concentrated in large superclusters of galaxies, each measuring 100 to 200 million light years across and each containing millions of galaxies. The galaxies are grouped in rich or poor clusters, have different shapes and are distributed in different ways. The galaxies contain stars and clouds of gas and dust. Stars may be grouped in clusters or they may be individual stars like the Sun having planetary systems like our Solar System. Our planet Earth is a part of the Sun's family.

Don't the diversity and the expanse of the universe seem truly amazing? Lost somewhere in the vastness of space and immensity of time is our tiny planetary home. This is a humbling thought. Yet, our species is young, curious and brave. We would rather not feel overwhelmed by the expanse of universe in space and time. We would like to end this unit with the words of Carl Sagan from his book 'Cosmos' (p.1):

Carl Sagan is a renowned American astronomer

"The Cosmos is all that is or ever was or ever will be.......... In the last few years, we have made the most astonishing and unexpected discoveries about the Cosmos and our place within it, explorations that are exhilarating to consider. They remind us that humans have evolved to wonder, that understanding is a joy, that knowledge is a prerequisite to survival. I believe our future depends on how well we know this Cosmos in which we float like a mote of dust in the morning sky."

## 9.4 SUMMARY

In this unit, we have tried to present a picture of the universe as a system, what the picture is now and how it has changed ever since human beings watched the heavenly objects and wondered about what they were. Let us now summarise what we have studied so far.

- For our prehistoric and Bronze Age ancestors, the Earth was at the centre of the universe. The dark heavens beyond were a mystery to them working under the control of some supernatural forces.
- The Greek philosophers tried to understand the universe on the basis of observations, logic and reasoning, and gave many models which were absorbed in the Ptolemaic geocentric model of the universe.
- Galileo's observations and later Kepler's formulation of the three laws of planetary motion based on the observations made by Tycho Brahe established the revolutionary heliocentric model.
- The discovery that the Sun was one of the millions of stars in the Milky Way and was located only at a large distance from the centre of the Galaxy led to the rejection of heliocentrism.
- We now know about the structure of the universe on a large scale. The planets, stars, galaxies, clusters, and superclusters form a dynamic universe which is always changing.

## 9.5 TERMINAL QUESTIONS

1) What was the need to look for a better model than Ptolemy's model of the universe? Give your answer in the space provided.

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2) Explain, in four or five lines, how Galileo's observations led to the rejection of Ptolemy's model?

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3) State in a sequence, the modern observations that have led to the rejection of heliocentrism and our current perception of the universe that it is vast and has no centre and no boundaries.

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4) State in the boxes given, whether the following statements about the universe are true or false:
   a) The Milky Way Galaxy is at the centre of the universe ☐
   b) Seen on a scale of distance larger than the superclusters, the universe seems the same everywhere. ☐
   c) The space between the stars and galaxies is empty. ☐
   d) We can see the edge of the universe. ☐
   e) The interstellar space is full of clouds of gases, dust, cosmic rays. Organic molecules have also been found in the interstellar matter. ☐
   f) The universe is vast, billions of light years in extent. It is also ancient, being about 15 to 20 billion light years old. ☐

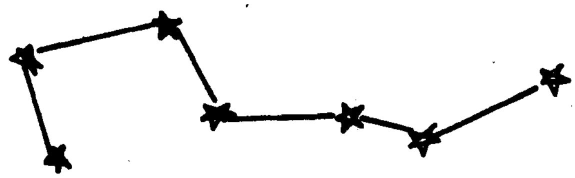
5) Match each of the entities listed in column 1 with their features given in column 2 below. Draw an arrow between the items that match.

| | 1 | | 2 |
|---|---|---|---|
| a) | Earth | i) | Groups of galaxies, containing a few to a few thousand galaxies. |
| b) | Sun | ii) | A group of stars arranged in a pattern, defining a region of the sky. |
| c) | Constellation | iii) | A tiny planet moving around the Sun. |
| d) | Milky Way Galaxy | iv) | A collection of clusters, extending upto several hundred million light years. |
| e) | Clusters | v) | A star situated at a large distance from the centre of the Milky Way Galaxy. |
| f) | Superclusters | vi) | A galaxy containing billions of stars, dust and gas. |

## 9.6 ANSWERS

**Self Assessment Questions**

1) a) To predict changing seasons, draw calendars, set the time for hunting, gathering tribes, sowing crops, reaping harvests etc.
   b) The ships seemed to sink below the horizon; the Earth cast a circular shadow on the Moon, during a lunar eclipse.
2) a) F  b) F  c) T  d) T.
3) a) Due to the observations of the heavens by Galileo.
   b) ii), iv).
4) a) Ellipse.
   b) Second Law: Planets move faster in their orbits when they are nearer to the Sun and slower when far away from it. Third Law: The more distant a planet is from the Sun, the more time it takes to complete a revolution around the Sun.
   c) Stellar parallax, i.e. the apparent shifting of nearby stars against the background of more distant stars when viewed from the Earth at an interval of six months.
5) a) 5,  b) 7,  c) 1.  d) 3,  e) 6,  f) 2,  g) 4.
6) a)

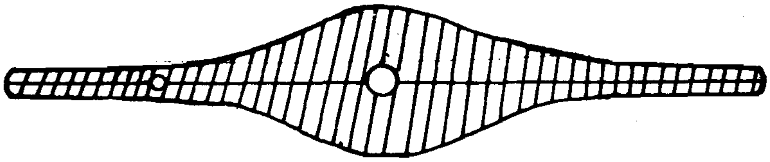


The star group *Saptarishi.*

   b) The star A is Pole star.
7) a) i) stars, gas and dust clouds, billions, ii) top, edge-on view, iii) disc, halo.

iv) clusters of stars, arms, between, v) sphere, large, little gas, a few stars, globular clusters, vi) galactic, globular, vii) halo, disc.

b)



8) a) i), iv), ii), v) iii).

| | |
|---|---|
| Earth | —All living beings, land, oceans, forests etc. |
| Solar System | —Sun, planets and their satellites, asteroids and comets. |
| Milky Way Galaxy | —Stars, clouds of gas and dust. |
| Clusters | —Galaxies. |
| Superclusters | —Clusters of galaxies. |

b) i) irregular, ii) elliptical, iii) spiral.

**Terminal Questions**

1) As the observations about planetary motion became more and more accurate, Ptolemy's model could no longer explain them.
2) The observation of the moons going around Jupiter showed a smaller version of Copernican model in the heavens. Secondly, the phases of the Venus could not be explained with the help of Ptolemaic system. The only way to explain these observations was that the Venus went around the Sun (see Fig. 9.3).
3) i) There were stars other than the Sun, which were not a backdrop to the Solar System but were objects scattered upto large distances in the vast space.
   ii) Solar System was a part of the Milky Way Galaxy, a huge collection of stars, gas and dust clouds.
   iii) The Sun did not lie at the centre of the Milky Way Galaxy.
   iv) There were other nearby galaxies similar to the Milky Way Galaxy such as the Andromeda Galaxy.
   v) The Milky Way Galaxy was one among the countless galaxies strewn in the vast space, no bigger than the others.
   vi) Galaxies grouped together to form clusters which were a part of giant superclusters scattered in space. Thus, the universe had no boundaries, neither any centre.

4) a) F b) T c) F d) F e) T f) T.
5) a) iii b) v c) ii d) vi e) i f) iv.