2 ORIGIN AND STRUCTURE OF THE EARTH

2.1. Introduction

The planet in which we live and move about is a unique and remarkable astronomical body. Geology, the science of the Earth, mainly concerns itself with the study of the Earth's constitution, structure, history and its evolution. The Earth is a member of the solar system. Solar system in turn is a member of the vast galaxy known as the Milky Way. Therefore, as an introduction to the study of geology, it is desirable to have some basic knowledge about the solar system and the vast universe in which millions and millions of stars and planets exist.

Our understanding of the universe has undergone serious revision in the last few centuries.

A **galaxy** is a vast assemblage of stars, nebulae, etc., composing an island universe separated from other such assemblages by great distances. The sun and its family of planets is part of a galaxy known as the **Milky Way Galaxy.** This galaxy has an estimated diameter of 100,000-150,000 light years. A light-year (symbol: ly), (sometimes written as lightyear) is an astronomical *unit of length* and it is equal to the distance that light travels in vacuum in one year. Light moves at a velocity of about 300,000 km each second. So in one year, it can travel about 9,500,000,000,000 km.

2.2. Solar System

The term **solar system** refers to a star and all the objects that orbit around it. Our solar system consists of the sun - our star and everything that travels around it. These include 8 planets and nearly 170 natural satellites (such as our moon); dwarf planets, countless asteroids (some with their own satellites), comets and other icy bodies and vast reaches of highly tenuous gas and dust known as interplanetary medium. It is located on the edge of a spiral arm (known as the **Orion Arm**) at one-half to two-thirds of the way (28,000 light-years) from the centre of our **Milky Way galaxy** (Fig 2.1). The whole solar system is moving around the galaxy with a period in a range of 220 to 250 million years. There are most likely billions of other solar systems in our galaxy. And there are billions of galaxies in the universe!

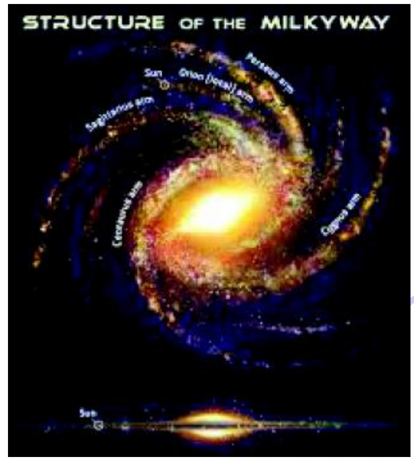

Fig. 2.1: Milky Way Galaxy and position of the Sun

The sun is the centre of our solar system. It contains almost all of the mass in our solar system and exerts a tremendous gravitational pull on planets and other bodies. Our solar system formed about 4.6 billion years ago. Two planets, Mercury and Venus, are closer to the Sun than the Earth. The four planets closest to the Sun - Mercury, Venus, Earth, and Mars - are called the **terrestrial planets** because they have solid, rocky surfaces. Two of the outer planets beyond the orbit of Mars - Jupiter and Saturn - are known as **gas giants**; the more distant Uranus and Neptune are called **ice giants**.

Until the time of Copernicus (1473–1553), it was generally believed that all celestial bodies in the universe revolved around the Earth. This concept of solar system is known as **geocentric concept**. With the invention of telescope, it was discovered by Galileo (1564–1642) that the Sun is the centre of the solar system and all planets including Earth are revolving around it. This gave rise to the **heliocentric concept**.

The orbits of the planets are ellipses with the Sun at one focus, though all except Mercury are very nearly circular (Fig. 2.2). The orbital paths of the planets are all more or less in the same plane. Planets orbit in the same direction (counter-clockwise while looking down from above the Sun’s north pole); all but Venus and Uranus also rotate in that same sense.

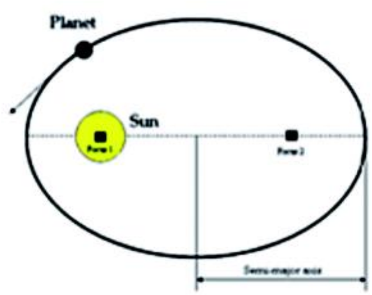

Fig. 2.2: Elliptical orbit of a planet

Most of the known dwarf planets exist in an icy zone beyond Neptune called the **Kuiper Belt**, which is also the place of origin of many comets. Many objects in our solar system have atmospheres, including planets, some dwarf planets and even a couple of moons.

The mean distance to the sun from our planet is 149.60 million kilometres. This distance is known as an **astronomical unit** (abbreviated AU), and it is used as a unit of length for measuring distances all across the solar system. One AU is roughly the average Earth–Sun distance (about 150 million km). NASA's Voyager 1 and Voyager 2 spacecrafts are the first spacecrafts to explore the outer reaches of our solar system.

2.2.1. The Sun

The Sun which occupies the centre of our solar system is a star. A star does not have a solid surface, but is a ball of hot ionized gas. The radius of the sun is 695,508 km, or about 110 times the radius of the Earth. One million Earths could fit inside the sun. The Sun has no solid surface. Its mass is approximately 330,000 times the mass of Earth and accounts for about 99.86% of the total mass of the entire solar system. Chemically, about three quarters of the Sun's mass consists of hydrogen, while the rest is mostly helium. The remainder (1.69%, which nonetheless equals 5,600 times the mass of Earth) consists of heavier elements, including oxygen, carbon, neon and iron, among others. The ionized gases are held together by gravitational attraction, producing immense pressure and temperature at its centre. Since the Sun is not a solid body, different parts of the sun rotate at different rates. At the equator, the sun spins once about every 25 days, but at its poles the sun rotates once on its axis every 36 Earth days. The surface temperature of the Sun is around 5,725 °C. The temperature at the Sun's core is about 15 million degrees Celsius.

Although the Sun is of no significance to the universe as a whole, it is earth's primary source of energy. The energy from the Sun is the driving force behind many processes taking place on Earth like winds, waves and currents, rain and climate etc. It is also responsible for the survival of varied forms of organisms of the Earth.

2.2.2. Planets

The solar system consists of eight planets (Fig. 2.3). They are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.

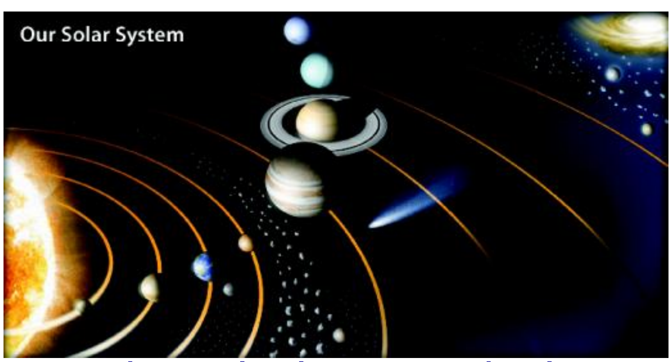

Fig. 2.3: The Sun and its planets constitute the Solar System

RELEVANT FACTS ABOUT THE PLANETS OF THE SOLAR SYSTEM

The planets are grouped into two classes as **inner planets** and **outer planets**. The first four planets – Mercury, Venus, Earth and Mars are called inner planets or terrestrial planets. The remaining planets – Jupiter, Saturn, Uranus and Neptune are known as outer planets or **Jovian planets**.

Mercury is the planet nearest to the Sun and it is also the smallest planet in our solar system - only slightly larger than the Earth's moon. Because Mercury is so close to the Sun, it is hard to directly observe from Earth except during dawn or twilight. Mercury orbits around the Sun every 88 days. Its orbital speed is faster than that of any other planet. One Mercury solar day equals 175.97 Earth days. Venus is the hottest planet in the solar system. Its surface temperature is estimated as 465°C. Since the duration of rotation and that of revolution of this planet are almost the same (see the table 2.1) one day of Venus is slightly lengthier than its one full year. Neptune is the farthest planet and Jupiter is the largest.

Table 2.1: Some relevant facts about planets

Sl. No.	Name of Planet	Average Distance from Sun in Million km.	Equatorial Diameter in km.	Density. kg/m³	Time for one Revolution	Time for one Rotation (hours)	Mean Temperature (°C)	No. of Satellites
1.	Mercury	57.9	4,879	5427	88 days	1407 .6	167	0
2.	Venus	108.2	12,104	5243	224 days	-5832.5	464	0
3.	Earth	149.6	12,756	5514	365¼ days	23 .9	15	1
4.	Mars	227.9	6,792	3933	109 years	24.6	-65	2
5.	Jupiter	778.6	1,42,984	1326	11.9 years	9.9	- 110	67
6.	Saturn	1433.5	1,20,536	687	29.5 years	10.7	- 140	62
7.	Uranus	2872.5	51,118	1271	84 years	-17.2	- 195	27
8.	Neptune	4495.1	49,528	1638	164.9 years	16.1	- 200	14

2.2.3. Asteroids

Asteroids are smaller celestial bodies which revolve around the Sun. Most of them have their orbits in between those of Mars and Jupiter. They are made up of rocky materials and have varying sizes and shapes. The largest one, 'Ceres', is about 1000 km. in diametre. Recently Ceres is included among the group of dwarf planets along with Pluto and some others. The discovery of this celestial body was made on January 1st, 1900.

Most of the known asteroids, numbering over 50,000, have only about 1km diametre. Scientists generally believe that asteroids are fragmental remains of some pre-existed planet that has been shattered by some unknown process.

2.2.4. Comets

Comets are smaller celestial bodies revolving around the sun in highly elliptical and elongated orbits (Fig. 2.4). The majority of them spend most of their time in the outer reaches of the solar system, occasionally coming very close to the sun.

Fig. 2.4: Comet

When a comet comes closer to the sun, its contents such as ice particles, carbon dioxide etc. get evaporated. The comets have a rocky nucleus and a long luminous tail made up of gases, ice and dust particles, directed away from the sun. The gases form a halo around the nucleus which may be visible from the Earth when a comet comes closer to the sun. There is a well known comet the Halley's Comet, named after Edmund Halley a famous astronomer of the eighteenth century. This comet appears in the neighbourhood of the earth once in 76 years.

THE OORT CLOUD

In 1950, the Dutch astronomer Jan Oort proposed that certain comets come from a vast, extremely distant, spherical shell composed of icy bodies surrounding the solar system. This giant swarm of objects is now named as the **Oort cloud**, occupying space at a distance between 5,000 and 100,000 astronomical units from the Sun. Some of the comets belonging to the Oort cloud have very large, eccentric orbits and take thousands of years to circle the Sun. In recorded history, they are observed in the inner solar system only once. In contrast, short-period comets take less than 200 years to orbit the Sun and they travel approximately in the plane in which most of the planets orbit. These comets are presumed to come from a disc-shaped region beyond Neptune, called the **Kuiper Belt**, named in honour of astronomer Gerard Kuiper. The Kuiper Belt extends from about 30 to 55 AU from the Sun and is probably populated with hundreds of thousands of icy bodies larger than 100 km across and an estimated trillion or more comets.

Let us do

Prepare a model of solar system, using an appropriate scale (for eg. 1 metre = 2AU) in a convenient location of your school compound.

2.2.5. Meteors and Meteorites

Most of you are familiar with the event of a sudden and bright streak of light moving across a moonless night sky and disappearing after a few seconds without leaving a trail behind. This phenomenon is caused by the members of the solar system known as **meteors**.

Meteors are small celestial bodies which enter the earth's atmosphere from interplanetary spaces and burn by friction with the particles of the earth's atmosphere, producing a streak of light across the sky. The heating resulting from friction causes the burning of the body of the meteor within the atmosphere. Meteors are rock fragments from space which travel at great speeds of several km/second. Thousands of meteors enter the earth's atmosphere every day. Sometimes there are meteor showers that originate from "the debris" of the tails of the comets. Incompletely burnt meteors reaching the surface of the earth are called **meteorites**.

The impact of huge meteorites produces impact craters on the surfaces of the earth. A well known impact crater is the Meteor Crater (Barringer Crater) of Arizona Desert in U.S.A (Fig. 2.5). The crater is about 1.2 kilometre across and 200 metre deep. An Indian example of impact crater is the Lonar Crater (a saline soda lake) with a diametre of 1.8 km, located at Lonar in Buldana district, Maharashtra. It was created by a meteor impact on Deccan lava flows, during the Pleistocene Epoch.

There are three types of meteorites:

a) Stony meteorites, b) Iron meteorites and c) Stony - iron meteorites

Fig. 2.5: Meteor Crater (Barringer Crater) of Arizona, USA

There are two reported meteorite finds from Kerala. One from Cranganore (Kodungalloor) which fell in 1917 at 10°12'N, 76°16'E, weighing about 1460 g and another one from Kuttipuram (10°50'N, 76°2'E) collected in 1914 and weighing about 45 kg. Both of these are chondrites or stony meteorites.

This grouping is based on the composition of the meteorite. Stony meteorite mainly consists of silicates. The iron meteorite is made up of iron alloyed with nickel and other metals. Stony iron meteorites consist of a mixture of silicates and iron. Most meteorites are of stony variety. Only very few are a mixture of stone and iron.

Meteorites are valuable to science because they are the only objects that come to us from outside the earth and therefore are especially valuable as they give clues regarding the age of the solar system. They also give information about certain chemical aspects of the solar system.

2.3. Origin of the Universe -The Big Bang Hypothesis

Today, from our tiny homeplanet- Earth, our scientists are using their ingenuity, and probing the depths of the Universe and trying to unravel its mysteries. The origin of the universe is a most complex topic, only a very brief discussion of which is given below.

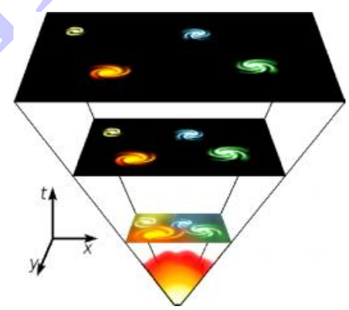

Fig 2.6: Concept of an expanding universe

The universe contains all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe also includes all of space and time. Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. **Redshift** is a shift of element lines toward the red end of the spectrum. Redshift occurs when the source of light is moving away from the observer. Hubble noticed a relationship, which is now called Hubble's law: *The farther away a galaxy is, the faster it is moving away from us.* The farther away a galaxy is, the more its light is redshifted, and the faster it is moving away from us. In other words, the universe is expanding! You'll notice that the galaxies that are farther away in distance are travelling at higher velocities.

Imagine a balloon covered with tiny dots (Fig. 2.6). Let us say that each dot represents a galaxy. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If it was a giant balloon and you were standing on one of the dots, you would see the other dots moving away from you. Not only that, but dots farther away from you on the balloon would move away faster than dots nearby. Note that the distance between galaxies gets bigger as you go forward in time, but the size of each galaxy stays about the same.

The discovery that the universe is expanding also told astronomers something about how the universe might have formed. Before this discovery, there were many ideas about the universe, most of them thinking of the universe as constant. Once scientists learned that the universe is expanding, the next logical thought is that at one time it had to have been smaller. The current expansion of the universe suggests that in the past the universe was squeezed into a very small volume.

The **Big Bang** is the name of a widely held scientific theory of the evolution of the universe. To understand this theory, start by picturing the universe expanding steadily. Then, reverse the direction of time, like pressing the "rewind" button on a video player. Now the universe is contracting, getting smaller and smaller. If you go far enough back in time, you will reach a point when the universe was squeezed into a very small volume.

According to the Big Bang theory, the universe emerged from a highly compressed primitive state with extremely high temperature and density with no stars, atoms, form or structure - called a "**singularity**". Initially, the universe was concentrated at a single point. The theory states that the universe expanded rapidly with a tremendous explosion, from its highly compressed primordial state, which resulted in a significant decrease in density and temperature.

The Big Bang started somewhere about 13.7 billion years ago. In the first few moments after the Big Bang, the universe was extremely hot and dense. As the universe expanded, it became less dense and it cooled. After only a few seconds, the universe had cooled enough that protons, neutrons, and electrons could form. After a few minutes, the nuclei of atoms formed. The first neutral atoms with neutrons, protons, and electrons, did not form until about 380,000 years after the big bang. The matter in the early universe was not smoothly distributed across space. Some parts of the universe were denser than others. These clumps of matter were held close together by gravity. Eventually, these clumps became the protogalaxies and within them the earliest stars. Stars are nuclear furnaces in which heavier elements such as carbon, oxygen, silicon and iron are formed. Massive stars exploding as supernovae create even heavier elements. Such explosions send material into space ready to be incorporated into future generations of stars and planets and other structures that we see in the universe today.

Both time and space were created in Big Bang event.The Big Bang might also have been the beginning of time. If the Big Bang was the beginning of time, then there was no universe before the Big Bang, since there was no concept of "before" without time. Other ideas state that the Big Bang was not the beginning of time; instead, some believe that there was a different universe before and it may have been very different from the one we know today.

Now, some of you may be curious to know the answers to the questions: What is the rate of expansion of our universe? Will the universe expand and its size grow forever?

Many scientists believe that, the expansion of the universe cannot continue forever, but the process of expansion will stop some day in the remote future. When the expansion stops, it will begin to contract due the gravitational force between the galaxies and matter present in the universe. This gravitational collapse can be called as the 'Big Crunch'. At the end of the Big Crunch, singularity may again take place. And this may lead to the next Big Bang! In short our universe will oscillate between alternate phases of expansion and contraction.

2.4. Origin of the Earth

How was this planet born? Where did it come from? These questions agitated the minds of scientists, and escaped satisfactory explanations for a long time. Even today the answers to those questions remain not fully satisfactory (Fig. 2.7).

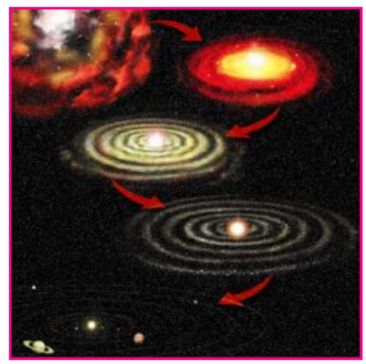

Fig. 2.7: Origin of the Earth

Regarding the origin of earth, several views appeared during the last 250 years. Most of these are given only the status of *hypotheses* rather than that of *theories*.

Let us learn in brief two important early hypotheses that attempted to explain the origin of earth.

2.4.1. The Nebular Hypothesis

Early attempts to explain the origin of this system led to the Nebular Hypothesis. This was originally proposed by a German Philosopher, Immanuel Kant in 1755 and later in 1796, the French astronomer/ mathematician Pierre Simon de Laplace modified and elaborated it.

According to the Nebular Hypothesis, the solar system evolved from a cloud of dispersed particles- a large, primordial **nebula**. This term, derived from Latin (meaning "mist" or "cloud"), refers to any of the various tenuous clouds of gas and dust that occur in interstellar space (that part

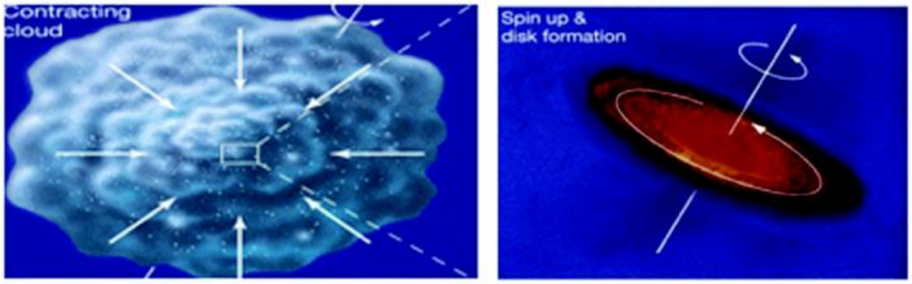

Fig. 2.8: (a), (b) - Nebular Hypothesis

of the space in between stars). According to the nebular hypothesis, part of an interstellar cloud of dust and gas underwent gravitational collapse (contraction) to form a primeval solar nebula (Fig. 2.8a). After contraction, it began to spin and transformed into a disc (Fig. 2.8b).

Clumps of interstellar matter were left behind in the midplane of the solar disc as it contracted towards its centre gradually coalesced, through a process of accretion, to form grains, pebbles, boulders, and still larger masses measuring a few kilometres to several hundred kilometres across. These larger building blocks then combined under the force of gravity to form protoplanets, which were the precursors of most of the current planets of the solar system. Later these protoplanets accreted more materials, and assumed the size and shape of planets as we know them today. (Fig. 2.9 a and 2.9 b).

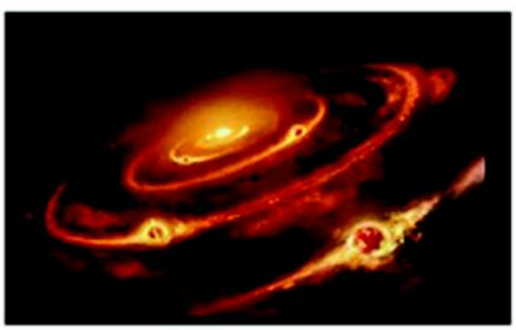

Fig. 2.9: (a) Evolving solar system

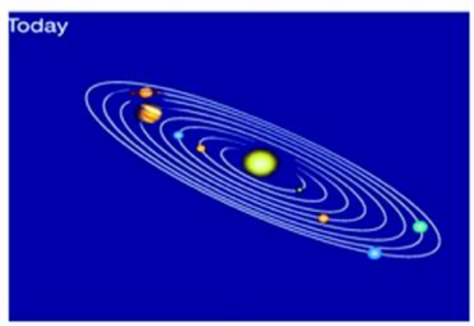

Fig. 2.9: (b) Present solar system

The asteroids and some other smaller celestial bodies are fragments left by the shattering of one or more of other planets so formed in the process. The remaining central mass of the nebula later formed the Sun.

2.4.2. Planetesimal Hypothesis

This hypothesis was proposed by the U.S. Geologist Chamberlin, and a U.S. Astronomer Moulton, in 1905. Planetesimals are one of a class of bodies that are theorized to have coalesced to form Earth and the other planets after condensing from concentrations of diffuse matter early in the history of the solar system. According to the planetesimal hypothesis, a star once passed near the Sun, pulling away from it matter that later condensed and formed the planets. This hypothesis postulates that due to an event of near approach of a passing star, very large tidal waves were created upon the surface of the Sun. Due to the extreme gravitational pull of the passing star, a portion of Sun's mass that formed a tidal swell was pulled far out into the space.

This ejected mass chilled out immediately resulting in the formation of innumerable small solid particles. These small particles, named as planetesimals, continued to revolve around the Sun in various nearly circular orbits. During the revolution, these swarms of planetesimals mutually collided and coalesced to form the planets. Therefore, the planets have been in solid form all the time during their growth, according to this hypothesis. This hypothesis explains the occurrence and occasional fall of meteorites. The Planetesimal Hypothesis could also give a satisfactory explanation for the known design (plane of rotation of planets) and other features (similar rotational directions of planets) of the solar system.

2.5. Shape and Size of the Earth

Until the 17th century, it was believed that the earth was a perfect sphere. Later scientists discovered that the Earth has a shape of an **oblate ellipsoid**. (If you slightly press down a sphere it will assume the shape of an oblate ellipsoid).

The Earth's polar axis is slightly shorter than its equatorial axis. This is attributed to its rotation about its polar axis and consequent effect of the resulting centrifugal forces (Fig. 2.10). The equatorial radius of the earth is 6378 km while its polar radius is 6357 km. Note that the equatorial diameter of the Earth is 42 kilometre longer than its polar diametre.

Elevation of a point on the Earth's surface is expressed with reference to **mean sea level**. It was once believed that the sea was in balance with the earth's gravity and formed a mathematically regular figure. The mean sea level is usually described as the arithmetic mean of hourly water elevations caused by tidal effect (of the gravitational forces from the Moon and Sun) observed over a specific 19-year cycle. Since the sea

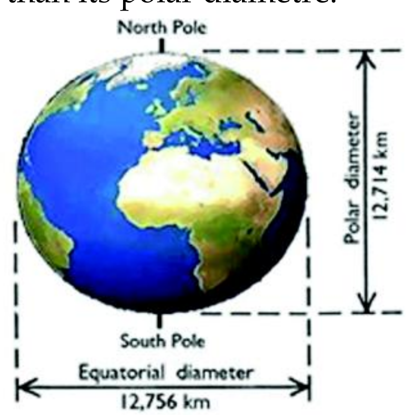

Fig. 2.10: Oblate ellipsoidal shape of the Earth

surface conforms to the earth's gravitational field, mean sea level also has slight hills and valleys that are similar to the land surface but much smoother. Modern studies have indicated that the actual shape of the earth is not truly that of a mathematically true oblate ellipsoid. Scientists have noticed the fact that while some parts of the earth's surface are higher than the surface of a mathematically true oblate ellipsoid other regions are below that surface (Fig. 2.11). The true form or shape of the earth is today described by the scientific term '**geoid**'. If we cut numerous canals from one side of the continent to the other in different directions and allow the ocean water to occupy the canals, the surface formed by connecting the water surfaces of the canals will give the true form described by the term geoid.

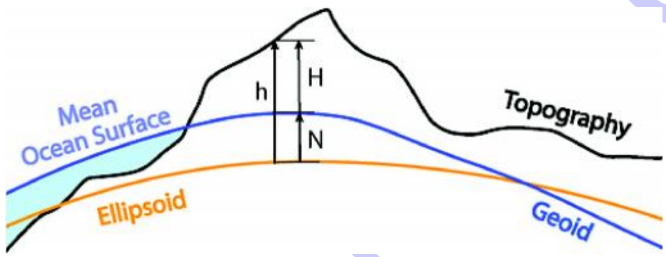

Fig. 2.11: Relationship between ellipsoidal surface, mean sea level and geoidal surface

2.6. Concept of Geologic Time

One of the most important modern developments in Earth Science was the determination of the age of the solar system and its family of planets and satellites. Scientists generally agree on the point that our earth is about 4500 million (4.5 billion) years old. The term '**geologic time**' is given for the entire duration of time since the formation of the earth to the present day.

2.6.1. The Geologic Time Scale

According to the present scientific estimate our earth is about 4.54 ± 0.05 billion years (4.54×10^9 years ± 1%) old. This age is based on evidence from radiometric age dating of meteorite material and the ages of the oldest - known rocks samples of the Earth.

The **geologic time scale** is a system of chronological measurement used by earth scientists to relate the timing and relationships between events that have occurred during the Earth's history. However, that segment of Earth history that is represented by and recorded in rock strata extends only from about 3.9 billion years ago (corresponding to the age of the oldest known rocks) to the present day. It is, in effect, that segment of Earth history that is represented by and recorded in rock strata.

Table 2.2: Geological Time Scale (with their duration in millions of years)

Eon	Era	Period	Epoch
Phanerozoic 542 to present	Cenozoic (65 my to present)	Quaternary (2.6 - present)	Holocene (0.1 to present)
			Pleistocene (2.6-0.1)
		Tertiary (66 – 2.6)	Pliocene (5.3- 2.6)
			Miocene (23- 5.3)
			Oligocene (34-23)
			Eocene (56-34)
			Palaeocene (66-56)
	Mesozoic	Cretaceous (145 - 66)	
		Jurassic (201 - 145)	
		Triassic (247 - 201)	
	Palaeozoic	Permian (299 - 247)	
		Carboniferous (359 -299)	
		Devonian (419 -359)	
		Silurian (445 - 419)	
		Ordovician (485 - 445)	
		Cambrian (541 - 485)	
Proterozoic (2500 - to 542)	Neoproterozoic (1000 - 541)		
	Mesoproterozoic (1600- 1000)		
	Paleoproterozoic (2500 - 1600)		
Archaean (4000 to 2500)	Neoarchaean (2800 - 2500)		
	Mesoarchaean (3200- 2800)		
	Paleoarchaean (3600 -3200)		
	Eoarchaean (4000 - 3600)		
Hadean (about 4600 – 4000)			

Dates given are in millions of years (my)

The geologic time, as it is known today, is subdivided into a number of named time units. The term **geologic time scale** is applied for the time scale consisting of various named divisions of the geologic time (Table 2.2). The time span *right from the birth of the earth* up to the present day is divided into many units - larger and smaller time units. The major division of this duration of time is given below:

(1) **Eons :** The Geological time from the birth of the Earth to the present is divided into four grand divisions called eons. The oldest eon is (1) **Hadean Eon** (starting from 4600 million years to about 4000 million years), (2) **Archaean Eon** (starting from 4000 million years to 2500 million years) (3) **Proterozoic Eon** (starting from 2500 million years to about 541 million years) and the youngest (4) **Phanerozoic Eon** (starting from 541 million years to present).

(2) **Eras:** Eras are the subdivisions of eons. *There are no subdivisions for the Hadean Eon.* Archean Eon is subdivided into four eras (the oldest being **Eoarchean Era**, followed by **Paleoarchean Era**, **Mesoarchean Era** and the youngest **Neoarchean Era**).

The Proterozoic Eon is similarly subdivided into three eras (namely the **Paleoproterozoic Era**, the **Mesoproterozoic Era** and the youngest **Neoproterozoic Era**).

Phanerozoic Eon is divided into three eras (the oldest one being the **Palaeozoic Era**, followed by the **Mesozoic Era** and the youngest, the **Cenozoic Era**).

The term **Precambrian** (**Pre-Cambrian**) is generally used to describe the large span of time in earth's history before the current Phanerozoic Eon.

(3) **Periods:** Some eras are further subdivided into smaller time units called periods. Thus the Phanerozoic Eon consists of eleven periods. They are in order : the Cambrian Period (the oldest period of the Palaeozoic Era), the Ordovician Period, the Silurian Period, the Devonian Period, the Carboniferous Period (the Mississippian and the Pennsylvanian) , the Permian Period (the youngest period of the Paleozoic Era), the Triassic Period (the oldest of the Mesozoic Era), the Jurassic Period, the Cretaceous (the youngest period of the Mesozoic Era), the Tertiary Period (the oldest of the Cenozoic Era), and the Quaternary Period (the youngest period of the Cenozoic Era).

(4) **Epochs:** An epoch is a subdivision of the periods of the geologic time scale. We are currently living in the Holocene Epoch of the Quaternary Period.

Check your progress

1. *What is the peculiar shape of the Earth?*
   How does it affect the Earth's circumference and radius?
2. *What is meant by Geologic Time?*
3. *Which is the latest epoch of the Geologic Time Scale?*
4. *What do you mean by the 'Big Bang' ?*

2.7. Internal Structure of the Earth

If we could make a journey to the centre of the earth we would have to travel about 6,400 km. Along the way to earth's centrally located core we would pass layers of rock that can be classified in two different ways, either by their *chemical composition* or their *physical behaviour*. According to the chemical composition of the rocks, earth's interior can be differentiated into three layers - crust, mantle, and core. When considering the rocks of earth's interior in terms of their physical behaviour, six layers can be differentiated from the surface to the core. The characteristics that distinguish these six different layers are based on the relative strength of a given layer in response to stress and irrespective of whether it is solid or liquid.

The chemical composition and physical behaviour of rock inside the earth relate to each other because the chemical composition of a rock is one of the factors that determine its physical behaviour. However, the physical behaviour of rock also depends on the pressure and temperature it is subjected to at its depth within the earth. As depth inside the earth increases, the pressure and temperature increase. Some layers in the earth are harder or softer than adjacent layers, *even though they have the same composition*, because they are at different pressures and temperatures. Fig 2.12 represents the interior of the earth showing all the inner layers.

(1) Crust

Our tour to the centre of the earth starts at the surface with earth's crust. Crust is the outermost division of the solid earth. Although all the three types of rocks, namely igneous, metamorphic and sedimentary, are found here, the first two constitute volumetrically dominant portion of the crust. The thickness of the crust is variable from region to region and is not uniform everywhere. Beneath the oceans, the crust is generally 5 km to 10 km thick whereas, on continental areas it has an average thickness of about 35 km. In regions of major mountains, such as the Himalayas, the thickness

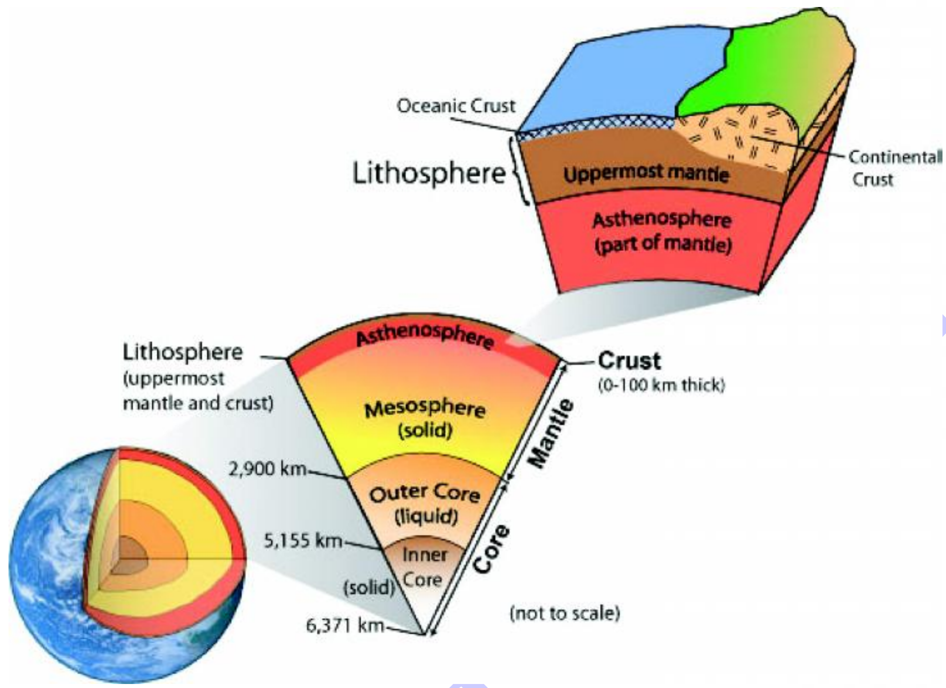

Fig. 2.12: Interior of the Earth showing all inner layers

of the crust is estimated to exceed 70 km. A prominent seismic discontinuity, known as Mohorovicic discontinuity or simply 'Moho' is considered as the boundary separating the overlying crust from the underlying mantle, which is the second interior division. Generally speaking, the crust is predominantly silicon oxide and aluminum oxide. Continental crust is thicker and less dense than oceanic crust. Earth's crust varies in thickness from less than 5 km (under mid-ocean ridges) to more than 70 km (beneath the highest mountain range).

The concept of Sial and Sima: The rocks of the crust composed predominantly of silicates of aluminium have relatively lower density ranging from 2.7 – 2.8 g/cm^3. These rocks, in bulk composition are similar to the rocks called granite. These rocks have the minerals feldspars (an aluminosilicate mineral series) and quartz (crystalline silica) as their dominant minerals. Because of their relatively lower density compared to other common rocks of the crust, these tend to be concentrated in the upper portion of the crust. The upper layer of the Earth's crust is the continental portions, and these are predominantly composed of granitic rocks. The name sial (taking the first two letters of the words **silica** and **aluminium** - which are the dominant elements of granitic rocks) is therefore given to this portion (continental portion) of the crust. The term felsic, (derived from the words feldspars and silica), is also used for this portion of the crust (the continental crust) which is made up mostly by rocks enriched in silicates of aluminium. Sial is absent in the oceanic part of the crust.

The crustal portion that underlies the sial is often exposed in the ocean basins where they are not blanketed by marine sediments. The ocean floors are mainly composed of the volcanic rock called **basalt**. These rocks are composed predominantly of **silica** and **magnesium**. This lower layer of the crust has relatively higher density (2.8 to 3.3 g/cm^3) than the sial due its relatively greater content of iron and magnesium, and decreased amounts of aluminium. Therefore, the term **sima** (taking the letters **si** from the word silica and **ma** from magnesium) has been given to this portion of the crust i.e., the 'oceanic crust'. It is also called the basaltic layer of the crust. Because it is the lower portion of the crust this portion of the crust is also known as the **'basal crust**' or **'basal layer**'.

The boundary of the sial and sima (known as the Conrad discontinuity) is not a clearcut one and it has been arbitrarily set at a mean density of 2.8 g/cm^3. Sima behaves like a very viscous liquid, the sial floats on the sima, in what is called isostatic equilibrium. Mountainous portions of continents (sial) extend deep down into the sima, much like roots of floating icebergs on an ocean. These divisions of the Earth's interior (sial and sima) were first proposed by Eduard Suess in the 19th century, and still frequently appear in geologic writings.

(2) Mantle

Mantle is the middle division of the earth (recognized on the basis of chemical composition). It extends from the bottom of the crust or Mohorovicic discontinuity down to a depth of nearly 2900 km from the earth's surface. In terms of volume, the mantle is the largest of earth's three chemical layers. Mantle occupies about 83% of the earth by volume and about 68% by mass.

The mantle has an **ultramafic composition** - it contains more iron, magnesium, less aluminum and somewhat less silicon than the crust. It is assumed that the rocks of upper mantle are dominantly composed of the silicate minerals olivine and pyroxenes. The lower boundary of the mantle is marked by a discontinuity known as Guttenberg-Weichert Discontinuity.

(3) Core

Our final stop in our journey, is the core, which is the innermost part of the earth. It starts at 2900 km below the surface and extends up to the very centre of the earth. Core is mostly iron and nickel. The radius of the core is about 3,500 km. It constitutes around 17% by volume and 34% of the mass of the earth. The pressure and temperature reaches up to 6000^{o} C.

When we consider the layers of the Earth's interior in terms of their physical behaviour, six layers can be differentiated from the surface to the core:

(1) Lithosphere: Starting at the surface, the first layer is the lithosphere. We humans, and the other creatures that live on earth, occupy the surface of the lithosphere. The lithosphere is entirely solid except where there are zones of magma beneath volcanoes or in places undergoing magma intrusion. The volume of molten rock in the lithosphere is a tiny fraction, less than 0.1%, of the volume of the entire lithosphere.

The lithosphere itself has two parts. The top part is the crust. The bottom part is the upper portion of the mantle – the **lithospheric mantle**. The two components of the lithosphere, in combination, form a relatively strong, rigid layer of rock that covers the earth. Earth's **tectonic plates**, (which you will learn in unit 11) all of which are in motion relative to each other, make up the lithosphere.

(2) Asthenosphere: Beneath the lithosphere is a relatively weak and ductile layer of the mantle called the asthenosphere. Although the asthenosphere is solid, not liquid, it flows at geological rates, up to several centimetres per year. In other words, the asthenosphere behaves more plastically than the rigid lithosphere above it.

The chemical composition of the asthenosphere is about the same as the chemical composition of the overlying lithospheric mantle. Why, then, is the asthenosphere soft and the lithosphere rigid? It is because at the depth of the asthenosphere, temperatures are very close to the melting point of the rock, weakening the rock. In fact, it is thought likely, from indirect evidence, that there is a small percentage of molten rock in the tiny spaces between the mineral grains of the asthenosphere, which contributes to the soft nature of the rock. However, the solid minerals of the asthenosphere are extensively in contact with each other, forming a material that is solid overall despite the possible presence of a small amount of partial melt.

The asthenosphere is the primary source of most magma. Because the asthenosphere is close to its melting point and may contain everywhere a small proportion of partly molten rock, it does not take much to cause magma to form and separate from the asthenosphere. Melting of the asthenosphere can be caused by addition of fluid, particularly water, or by a decrease in pressure.

(3) Upper mesosphere: Beneath the asthenosphere is the rest of the mantle, the mesosphere. The mesosphere makes up most of the volume of the mantle. It is entirely solid. The temperature and pressure of the rock in the mesosphere keep it from breaking; therefore, *no earthquakes originate from the mesosphere.*

The upper mesosphere is a transition zone in which the rock rapidly becomes denser with depth in response to the increasing lithostatic pressure.

(4) Lower mesosphere: The lower mesosphere starts at a depth of 660 km from earth's surface. At that depth there is an abrupt increase in density. This increase is caused by changes in the crystal structures of the most abundant minerals in the rock. These minerals change from less dense crystal structures above the boundary to more dense crystal structures below the boundary. The lower mesosphere undergoes little density change from its top boundary at 660 km to its base at 2900 km where it meets the outer core.

(5) Outer core: The bottom of the mesosphere is the boundary with the earth's core. The core is about twice as dense as the crust, and about 1.5 times as dense as the mantle. The outer core is liquid, as was discovered when it was first observed that S-waves (seismic or earthquake waves) will not pass through it.

(6) Inner core: The inner core is solid. The inner and outer cores are made of the same iron-rich, metallic composition. The temperature of the inner core is not very much greater than the temperature of the outer core. However, lithostatic pressure keeps increasing with depth and the inner core has the great weight of the rest of the earth pressing in on it. The pressure on the inner core is high enough to keep it in the solid state.

The following table 2.3 summarizes the physical layers of the earth.

Table 2.3 Physical layers of the Earth

	Physical behaviour	**Thickness**
1. Lithosphere	Rigid, brittle at shallow depths	5 to 200 km
2. Asthenosphere	Ductile	100 to 300 km
3. Upper Mesosphere	Rigid, not brittle, rapid increase in density with depth	300 to 400 km
4. Lower Mesosphere	Denser and more rigid than upper mesosphere	2,300 km
5. Outer Core	Liquid	2,300 km
6. Inner Core	Rigid, not brittle	1,200 km

Check your progress

1. *What are the different layers of the Earth?*
2. *Differentiate between outer core and inner core.*

Let us do

1. *Construct a three dimensional model showing the internal structure of the Earth.*
2. *Prepare a table as given below, showing the chemical and physical characteristics of the various layers of the Earth.*

	Crust	*Mantle*	*Core*
Chemical Characteristics			
Physical Characteristics			

2.8. The basic components of the Earth System

Earth system science is a new concept that treats the Earth as an integrated system and seeks a deeper understanding of the physical, chemical, biological and human interactions that determine the past, current and future states of the Earth. It provides a physical basis for understanding the world in which we live and upon which humankind seeks to achieve sustainability.

The Earth System has two primary components: the **geosphere** and the **biosphere**. The geosphere has four subcomponents: **lithosphere** (solid Earth), **atmosphere** (gaseous envelope), **hydrosphere** (liquid water), and **cryosphere** (frozen water). Each of these subcomponents can be further subdivided into *elements*: for example, the oceans are elements of the hydrosphere. The biosphere (living organisms) contains several phyla organized into five kingdoms of life forms. (Human beings belong to the Kingdom Animalia and are but one species of the estimated 20 million to 100 million species in the biosphere).

2.8.1. Lithosphere

Lithosphere is the outer rocky covering of the earth. The term lithosphere is used for a division of the Earth's interior comprising the crust and the upper part of the mantle. Lithosphere is composed of three types of rocks (igneous, sedimentary and metamorphic) and its products.

In modern texts and in Earth system science, the term **geosphere** refers to the *solid parts of the Earth* and is used along with **atmosphere**, **hydrosphere**, and **biosphere** to describe the major basic components of the systems of the Earth. *In that context, sometimes the term **geosphere** is used instead of the term lithosphere*. However, the *lithosphere only refers to the uppermost layers of the solid Earth (oceanic and continental crustal rocks and uppermost mantle).*

2.8.2. Atmosphere

The Earth is surrounded by a blanket of air called the atmosphere, which is a mixture of gases. Nitrogen, oxygen, carbon dioxide, and other gases are all parts of this mixture. Earth's atmosphere changes constantly as these gases are added and removed. For example, animals remove oxygen when they breathe in and add carbon dioxide when they breathe out. Plants take in carbon dioxide and add oxygen to the atmosphere when they produce food. Gases can be added to and removed from the atmosphere in ways other than through living organisms. A volcanic eruption adds gases. A vehicle both adds and removes gases.

The atmosphere also insulates Earth's surface by slowing down the rate at which heat from the sun is lost and it keeps Earth at temperatures at which living things can survive.

Composition of the Atmosphere

This gaseous composition of the atmosphere is usually expressed by percentage volume i.e., relative part of the total mixture. For example, 78.08 % of the atmosphere is made of the gas diatomic nitrogen (N_2), 20.95 % is composed of diatomic oxygen (O_2), and 0.93% is made up of argon (Ar). These three gases together make up 99.9% of the atmosphere. Nitrogen, which makes up the largest portion of air, is relatively inactive chemically. Much smaller amounts of water vapour (0 to 4% -highly variable in time and location), carbon dioxide (0.0395 % and presently rising), methane (0.00018 % and presently rising), and others are also present.

The atmosphere also contains solid material in addition to the gases noted above. This solid material is very small, between 0.1 and 25 thousandths of a millimetre, or micrometer and is known as **particulates**. These tiny, solid particles include dust which is mainly soil, salt, ash from fires, volcanic ash, solid products of combustion, pollen, and tiny liquid droplets called aerosols. In addition to gases and solids, liquids also exist in the atmosphere. The most common one of these is water in each of its

Let us do

Prepare a large pie diagram showing the relative percentage of the composition of the atmosphere.

three phases (solid, liquid, and gas), which has been essential for the development of life on the planet.

The gases of the atmosphere extend from the surface of Earth to heights of thousands of kilometres, eventually merging with the solar wind—a stream of charged particles that flows outward from the outermost regions of the sun. The composition of the atmosphere is more or less constant with height to an altitude of about 100 km, with particular exceptions being water vapour and ozone.

Air has weight and can exert pressure. Earth's atmosphere is pulled toward Earth's surface by gravity. As a result of the pull of gravity, the atmosphere is denser near Earth's surface. Almost the entire mass of Earth's atmospheric gases is located within 30 km of our planet's surface. Fewer gas molecules are found at altitudes above 30 km; therefore, less pressure at these altitudes pushes downward on atmospheric gases. Air is a powerful force on Earth exerting pressure on all organisms. Barometers are used to measure the air pressure. The typical pressure at sea level is 1013.25 millibars.

Vertical structure of the atmosphere (Layers of the Atmosphere)

The atmosphere begins at sea level (and in some places on land that are just below sea level) and extends outward some 10,000 km into space. The Earth's atmosphere can be divided into several layers. How the layers are defined can vary depending upon what properties are taken into consideration. We can define these layers based on many different properties of the atmosphere. Layers defined by different types of properties can overlap and the boundaries between layers are not sharply delineated.

Earth's atmosphere consists of two major vertical zones:

(1) **The homosphere** : This extends to an altitude of about 100 km. In this zone turbulent mixing dominates the molecular diffusion of gases and the composition of the atmosphere tends to be independent of height. Therefore the chemical composition of the atmosphere in the homosphere is highly uniform. The term homosphere is applied for this zone because of this fact.

(2) **The heterosphere :** This zone is located above 100 km from the Earth's surface. In this zone various atmospheric gases are separated by molecular mass, with the lighter gases being concentrated in the highest layers. Above 1,000 km, helium and hydrogen are the dominant species. Diatomic nitrogen (N_2), a relatively heavy gas, drops off rapidly with height and exists in only trace amounts at 500 km and above.

The transition zone, located at a height of around 100 km between the homosphere and heterosphere, is called the **turbopause**.

Based on temperature changes that occur at different distances above the Earth's surface, the homosphere, or **lower atmosphere**, is subdivided into four distint layers, and another three small intermediate layers that serve as *transition regions* from one layer to the next.

Figure 2.13 shows the vertical layers of Earth's atmosphere.

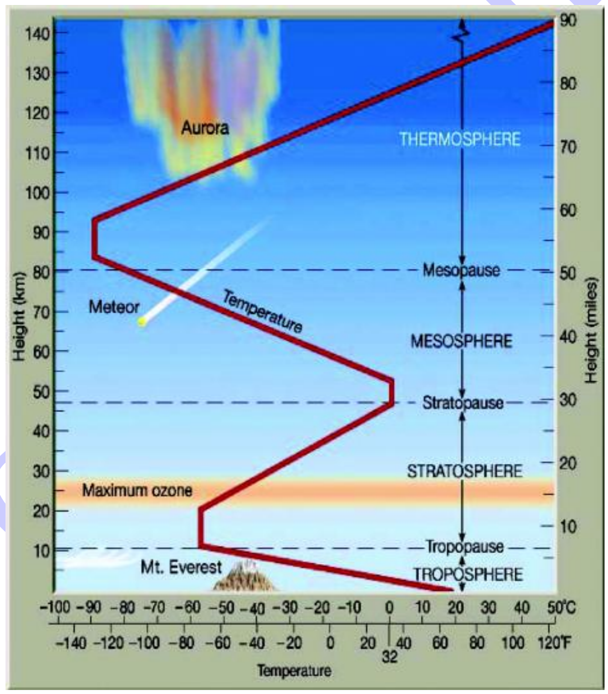

Fig.2.13: Layers of the Earth's atmosphere

(1) The troposphere

The troposphere is the inner or lowest layer of the atmosphere. Therefore, it is closest to the earth's surface and it is the layer that we live in. The troposphere is an extremely dynamic and ever changing system. Every day, the light, clouds, and heat energy in the troposphere go through a million variations. These changes affect daily life in thousands of subtle and direct ways and, for generations, humans have been fascinated by the troposphere's daily changes, which is known as weather. The behaviour of the gases in this layer is controlled by convection. This process involves the turbulent; overturning motions resulting from buoyancy of near-surface air that is warmed by the Sun. Because of convection, troposphere is a layer where temperature generally decreases with height. The name 'troposphere' comes from a Greek word *tropos* for "change" reflecting the fact that turbulent mixing plays an important role in this part of the atmosphere. And mixing is exactly what happens within the troposphere, as warm air rises to form clouds, rain falls, and winds stir the lands below. This mixing of air leads to the phenomenon of weather.

Troposphere extends only to a height of about 18 to 20 kilometres at the equator. Troposphere is thicker at the equator and thinner at the pole (where it may extend to only 7 km in winter).

The troposphere is the region where nearly all water vapour exists and essentially all weather occurs. The chemical composition of the troposphere is essentially uniform, with the notable exception of water vapour.

As light from the Sun reaches the ground, a portion of the solar energy reaching the troposphere is absorbed and converted into thermal energy and the latter spreads through the atmosphere by conduction and convection. The result is that the troposphere is warmest near the ground.

Typically, the higher you go in the troposphere, the colder it gets. Many of you may have experienced the fact that it is cooler on mountain tops than in the valleys. The rate at which the temperature decreases through the troposphere is called the *environmental lapse rate (ELR)*. In the troposphere, the average environmental lapse rate is about 6.5 °C per kilometre of elevation gain and at the top of the troposphere, the temperature is about -60°C. The region of the atmosphere where the lapse rate changes from positive (in the troposphere) to negative (in the stratosphere), is defined as the **tropopause**.

The troposphere contains most of the atmosphere's mass and 99% of the atomspheric water vapour and 75% atmospheric gases. It has abundant water vapour to propel the water cycle/and contains about 90% of the molecules in the atmosphere.

(2) The stratosphere

The stratosphere extends from the top of the troposphere (average value 14.5 km) to an altitude of about 50 kilometres above Earth's surface. In this layer of the atmosphere, *convective motions of air are weak or absent*; *here air flow is mostly horizontal*. The temperature in this layer increases with altitude. Stratosphere has almost no weather. The lower stratosphere is cold at about -60°C. High-altitude weather balloons can reach into the lower part of the stratosphere. In the stratosphere, there is a gradual temperature rise to about -3^{o}C resulting from the absorption of ultraviolet light by ozone (the "ozone layer"). In the lower stratosphere, temperature increases with height. Temperatures as high as 0 °C (32 °F) are observed near the top of the stratosphere. This is because of thermodynamic stability with little turbulence and vertical mixing. The warm temperatures and very dry air of this zone makes it almost cloud-free. When clouds do occur, these may be found up to a height of 30 km in the stratosphere and are called nacreous, or mother-of-pearl, clouds because of their striking iridescence. These clouds appear to be composed of both ice and supercooled water. These clouds form up to heights of 30 km.

In the upper stratospheric regions, absorption of ultraviolet light from the Sun dissociates or breaks down molecular diatomic oxygen (O_2); recombination of the resulting single oxygen atoms with O_2 molecules into ozone (O_3) creates the shielding ozone layer in the stratosphere. Natural stratospheric ozone is produced mainly in the tropical and middle latitudes. Ozone absorbs most of the dangerous ultraviolet light that comes from the Sun to the Earth. This protects us, on the surface, from this harmful radiation, but it also serves another purpose. The ozone converts the energy of the ultraviolet light into thermal energy, heating

WEATHER AND CLIMATE

Most of you may not have a full understanding about the relationship between ***weather*** and ***climate.*** It can be explained in terms of your checking account. The monthly balance for twelve months of a year would represent climate while the daily inputs and outflows of funds represent weather. Your daily balances might vary a great deal from day to day while your monthly balances, which are an average of your daily balances, would be more consistent. In the same manner, you know from your own experience that weather changes much more rapidly than climate. One day it might be warm and close to 40°C and the next day, cold and below 30°C. Climate also changes, but on a much longer time scale.

Daily changes in the troposphere are known as weather. Long term, average conditions are referred to as climate. Weather is more extreme than climate, meaning that daily ranges of temperature, precipitation, pressure, and wind are greater than the long-term extremes of climate. Since climate refers to long-term average conditions, it is more moderate. Almost all land-dwelling life forms are found in the bottom 5 kilometres of the atmosphere. At higher altitudes, the thin atmosphere and harsh conditions are inhospitable to most living organisms. Mt. Everest, at 8,848 m in elevation, extends about halfway into the troposphere.

the stratosphere. Regions of nearly complete ozone depletion, which have occurred in the Antarctic during the spring, are associated with nacreous clouds, chlorofluorocarbons (CFCs), and other man-made pollutants.

The stratosphere continues up to an altitude of about 45- 50 km and the **stratopause** is the transition region between it and the overlying mesosphere. Here, the atmospheric pressure is only 1 millibar. In this thin region, the temperature stops changing again. With the ozone layer heating it from below, the mesosphere is warmer at lower altitudes and cools at higher altitudes. This decreasing temperature with height continues throughout the mesosphere up to an altitude of about 80 km.

(3) The mesosphere

The atmospheric layer above the stratosphere is the mesosphere. It begins 50 kilometres above Earth's surface and extends to 80 kilometres. Temperature decreases rapidly upward and the mesosphere is the coldest layer of the atmosphere, and at the top its temperatures have been measured as low as –120°C.

Mesosphere is the region of the atmosphere where planetary and other debris entering the atmosphere begins to burn up. It thus protects Earth's surface from most meteoroids. They burn up as they fall toward Earth through this layer of the atmosphere (This is why the Earth's surface isn't pocked with meteor craters, like the moon's surface).

The **mesopause** separates the mesosphere from the overlying thermosphere, and it again has roughly the same temperature throughout the layer. This is the coldest layer. Although the air is thin, it is still thick enough to burn up meteors.

OZONE

A single molecule of oxygen (O_2) contains two oxygen atoms. But add another oxygen atom, and you have ozone. O_3 is a molecule of ozone that is made up of three oxygen atoms. In the stratosphere, ozone protects us, absorbing much of the sun's harmful ultraviolet radiation. But carried in the air we breathe at ground level (the troposphere), ozone is a poison that burns and corrodes living and non-living things. Small amounts of ozone develop naturally, especially during lightning storms, but industrial chemicals and automobile exhausts into the atmosphere, cook them with heat and sunlight, and ozone levels can rise dangerously high. Ozone is the main component of "photochemical smog."

(4) The thermosphere and ionosphere

The thermosphere is the layer of the Earth's atmosphere directly above the mesosphere and directly below the exosphere. The thermosphere begins about 85 kilometres above the Earth. At these high altitudes, the residual atmospheric gases sort into strata according to molecular mass (see turbosphere). Thermospheric temperatures increase with altitude due to absorption of highly energetic solar radiation. Temperatures are highly dependent on solar activity, and can rise to 2,000 °C (3,630 °F). Radiation causes the atmosphere particles in this layer to become electrically charged. The thermosphere extends outward into space, up to **thermopause**. Above about 100 km, the chemical composition of the atmosphere changes with altitude. This layer is known as the **upper atmosphere** or **heterosphere.** The **thermosphere,** the lowest layer of the heterosphere**,** extends outward several thousand kilometers with no real boundary between the upper atmosphere and space. It is the hottest region of the Earth's atmosphere. In this extremely thin atmosphere (with highly diluted gas in this layer) temperature can reach 2,500 °C during the day. Even though the temperature is so high, one would not feel warm in the thermosphere, because it is so near vacuum that there is not enough contact with the few atoms of gas to transfer much heat.The thermosphere is heated mostly by absorbing more ultraviolet radiation from the Sun. At an altitude of about 700 km. the temperature stops changing as we go higher, and the remaining atmosphere above this altitude is called the **thermopause**. Beyond this, the exosphere describes the thinnest remainder of atmospheric particles with large mean free path, mostly hydrogen and helium. As a limit for the exosphere this boundary is also called exobase. The exact altitude of thermopause varies by the energy inputs of location, time of day, solar flux, season, etc. and can be between 500–1000 km high at a given place and time because of these. Both the space shuttle and the International Space Station orbit in the middle-to-upper part of exosphere.

Within the thermosphere is a region known as the ionosphere. The ionosphere is not, technically, a separate layer of the atmosphere. It is a portion of the thermosphere where charged particles (ions) are abundant. These ions result from the removal of electrons from atmospheric gases by ultraviolet radiation reaching there from the sun. The ionosphere extends from about 80 to 300 km in altitude, and it is an electrically conducting region. This layer makes long-distance radio communication possible as it is capable of reflecting radio signals back to Earth. Auroras (northern and southern lights) also occur in thermosphere (Fig. 2.14).

Auroral displays consisting of attractive colours are the visible result of collisions between molecules in the atmosphere and incoming particles in the solar wind trapped by and traveling along magnetic field lines towards Earth's poles.

Fig. 2.14: Auroral lights

(5) The Exosphere

Beyond the thermosphere is the exosphere. It is the uppermost layer of the atmosphere, ranging from an altitude of about 700 km above sea level to about half way to the Moon, where the atmosphere thins out and merges with **interplanetary space**. The upper part of this layer is the beginning of true space. It is mainly composed of hydrogen, helium and some heavier molecules such as nitrogen, oxygen and carbon dioxide closer to its lower layers. The atoms and molecules are so far apart that they can travel hundreds of kilometres without colliding with one another, so the atmosphere no longer behaves like a gas. This tenuous portion of the Earth's atmosphere extends outward until it interacts with the solar wind. Solar storms compress the exosphere. When the sun is tranquil, this layer extends further outward. Its top ranges from 1,000 kilometers 10,000 kilometres above the surface, where it merges with interplanetary space.

The Greenhouse Effect

Sunlight that penetrates Earth's atmosphere heats the surface of the Earth. The Earth's surface radiates heat back to the atmosphere, where some of the heat escapes into space. The remainder of the heat is absorbed by greenhouse gases, which warm the air. Heat is then radiated back toward the surface of the Earth. This process, in which gases trap heat near the Earth, is known as greenhouse effect. Without the greenhouse effect, the Earth would be too cold for life to exist.

The gases in our atmosphere that trap and radiate heat are called **greenhouse gases**. None of the greenhouse gases have a high concentration in Earth's atmosphere. The most abundant greenhouse gases are carbon dioxide, methane, and nitrous oxide and together with water vapour they act like shields that protect the earth's surface. The quantities of carbon dioxide and methane in the atmosphere vary considerably as a result of natural and industrial processes, and the amount of water varies because of natural processes.

2.8.3. Hydrosphere

It is the term used for the total body of water of the earth. Earth's hydrosphere is a discontinuous layer of water at or near the planet's surface. In other words, all the natural waters occurring on or below the surface of the earth is known as Hydrosphere. Thus the term includes the oceans, seas, lakes, rivers, snow, ice, underground water and atmospheric water. In this sphere water is present in solid, liquid and gaseous forms i.e., ice, liquid water and vapour forms.

About 97% of the water of the hydrosphere is concentrated in oceans and seas as saline water. The remaining water is distributed in streams, lakes, glaciers, underground water systems and atmosphere. In terms of percentage, atmospheric water vapour is negligible, but the transport of water evaporated from the oceans onto land surfaces is an integral part of the hydrologic cycle that renews and sustains life.

The Hydrologic Cycle

After a short rain, you might have noticed a smoke like phenomena slowly rising upwards from warm road surface. What is the reason behind this process?

Here when the rain water falls on warm road, it changes its state to gaseous form through evaporation. This process is an important part of a major natural phenomenon called the **water cycle** or **hydrologic cycle** (Fig. 2.15).

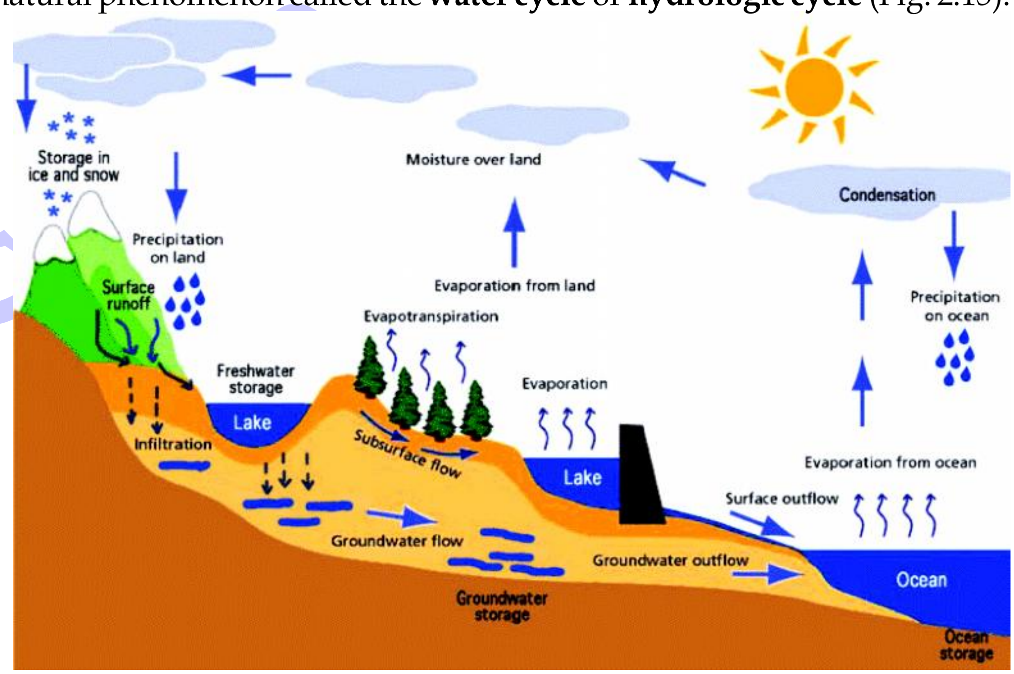

Fig. 2.15: Hydrologic cycle or Water cycle

The endless circulation of water through the different geospheres in solid, liquid and gaseous forms is called ***water cycle***. The hydrologic cycle or water cycle is composed of various processes, viz. 1) Precipitation, 2) Surface run-off, 3) Infiltration, 4) Base flow, 5) Evaporation, 6) Transpiration and 7) Condensation. These processes operate throughout the entire hydrosphere, which extends from about 15 km into the atmosphere to roughly 5 km into the crust.

Water reaches onto the surface of the earth in the form of precipitation. Rain and snow are the common types of precipitation.

After reaching the surface a part of the rain water is absorbed by the ground. This is called infiltration. The remaining water flows along the slopes towards oceans and lakes in the form of streams. The infiltrated water reaches the pore spaces of rocks and enriches the groundwater level. A portion of the infiltrated water flows through subsurface rock towards the oceans as **base flow**. This water is also absorbed by plants and trees, which is later evaporated through their leaves. This process is called ***Transpiration***.

Evaporation also takes place from rivers, lakes, oceans etc. The evaporated water then reaches the atmosphere and forms clouds. When the temperature in the troposphere drops sufficiently the cloud condenses and precipitation takes place.

The hydrologic cycle involves the transfer of water from the oceans through the atmosphere to the continents and back to the oceans over and beneath the land surface. About one-third of the solar energy that reaches Earth's surface is expended on evaporating ocean water. The resulting atmospheric moisture and humidity condense into clouds, rain, snow and dew. Moisture is a crucial factor in determining weather. It is the driving force behind storms and is responsible for separating electrical charge, which is the cause of lightning and thus of natural wildland fires, which have an important role in some ecosystems. Moisture wets the land, replenishes subterranean aquifers, chemically weathers the rocks, erodes the landscape, nourishes life, and fills the rivers, which carry dissolved chemicals and sediments back into the oceans.

2.8.4. Cryosphere

The temperature of some regions of the earth's surface are so cold that water in regions exist in solid state- ice or snow. Such regions of the Earth together constitute a component of the earth system called 'cryosphere' and these include the glaciated and ice covered regions.

Check your progress

1. *Why are ozone, water vapour and dust particles important to life on Earth?*
2. *Why is the troposphere called the 'weather sphere'?*
3. *What are the major gases present in the atmosphere?*
4. *What is the significance of the hydrologic cycle?*

2.9. Biosphere

Earth's biosphere can also be termed the **zone of life** on Earth. The term "biosphere" was coined by geologist Eduard Suess in 1875. Generally, the biosphere is defined as '*the global ecological system integrating all living beings and their relationships, including their interaction with the elements of the lithosphere, hydrosphere, and atmosphere*'.

Every part of the Earth, from the polar ice caps to the equator, features life of some kind. The actual thickness of the biosphere on earth is difficult to measure. Among larger animals, some birds (such as Rüppell's vulture) are know to fly at altitudes exceeding 11 km and some varieties of fish live underwater at depths exceeding 8 km., in deep sea trenches. The extent and range of microscopic organisms is still greater. Single-celled life forms have been found in the deepest part of the Mariana Trench, Challenger Deep, at depths of 11,034 metres. And microbes have been extracted from cores drilled more than 5 km into the Earth's crust in Sweden.

Our biosphere is divided into a number of biomes, inhabited by fairly similar flora and fauna. On land, biomes are separated primarily by latitude. Terrestrial biomes lying within the Arctic and Antarctic Circles are relatively barren of plant and animal life, while most of the more populous biomes lie near the equator.

All living beings of the earth including plants, animals and micro organisms constitute the Biosphere.

Let us sum up

The Earth is a unique and remarkable planet in solar system. The solar system consists of the sun, eight planets and their satellites, asteroids, comets and meteoroids. The solar system, in turn, is a member of the vast universe, which is believed to have formed from singularity by a 'big bang' about 13.7 billion years ago. There are several views regarding the origin of the Earth. The Geologic Time Scale refers to the entire duration of time since the formation of the Earth about 4.5 billion years ago.

The Earth is an oblate ellipsoid which causes slight differences in its equatorial and polar radii and circumferences. The true shape of the Earth is today described as a 'geoid'. The Earth is found to have a concentric layered structure distinguished on the basis of physical and chemical properties from its crust to the core.

The Earth system science treats the Earth as an integrated system that consists of a solid lithosphere, gaseous atmosphere, liquid hydrosphere and frozen water in the form of cryosphere. Biosphere is the zone of life on the Earth. The endless circulation of water through different spheres of the earth is called the hydrologic cycle.

Significant Learning Outcomes

The learner can:

- understand the earth's position in the solar system and get an awareness about the different members of the solar system.
- acquire an idea regarding the basic knowledge on the origin of the earth.
- acquire an awareness about the dimension of the earth, concept of geological time, internal structure of the Earth and identify the various major components of the earth system and their mutual relationships.

Let us assess

1. Define an astronomical unit? How many kilometres are one AU?
2. How does the earth's atmosphere act as a green house?
3. In which layer of the atmosphere temperature increases with altitude?
4. List out the characteristics of the different layers of the earth's interior.
5. At what depth does the earth's mantle begin?
6. What is nebular hypothesis?
7. What are the different Geologic time units?
8. What do you mean by the terms lithosphere and asthenosphere?