

Chapter 4

THE SOLAR SYSTEM

Sun, our own dear sun was formed about 5 billion years ago, from a cloud of dust and gas. Sun is a star, the nearest star to us. The happy birthday is about 5 billion years ago. It lies at the heart of our solar system. Sun can upset the balance of life on Earth. The sun makes a hundred million times more energy than all nine planets together. It is a huge fiery ball of gas composed of mostly hydrogen, then helium produced through a process called nuclear fusion. The temperature of sun is around $15,000,000^{\circ}\text{C}$. The power inside the sun blasts out its surface as visible light and heat and bathes the solar system in energy. We get only a billionth of the total energy output of the sun. It reaches earth to keep the life on the earth smoothly. Perhaps that is why sun was a God, the Egyptians called him as Ra, Greeks called him as Helios, the Persians Mithras, Romans called him as Apollo and the Indians, Adithya. In 500-428 BC Greek philosopher Anaxagoras told that sun is not a God.

Now we know that sun is middle aged and will die one day, because hydrogen dissolves in hydrogen through a process called nuclear fusion, hydrogen becomes helium and a hell of energy in the form of light, heat etc is produced. In every one second 5 million tonnes of matter is converted into energy. After certain time the sun will start using helium then it will shine 1000 times brighter than now and it will be 100 times bigger in size. Sun will consume first the planet Mercury and then Venus. Don't worry, our Earth is in a very fortunate position. But during that time Earth would become too hot and ultimately will become a massive ball of fire. After the sun becoming 100 times bigger, it will shrink to become a white dwarf of star, the size of the Earth. Then after thousands of millions of years later, it will cool down and end its life. Sun will be no more sun, it will be a cold dark body called a black dwarf, it will disappear from sight.

BIO-DATA OF SUN

- i. Name : G₂ star, relatively small, yellow
- ii. Age : approximately 5.6 billion years
- iii. Expected life span : probably another 5 billion years before it starts to die
- iv. Distance from the earth : 149,600,000 km
- v. Mass : just 2 billion billion tonnes, i.e. 330,000 times greater than that of Earth. Sun owns 99.8% of mass of the solar system

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vi. Surface gravity	: 38 times that of the earth
vii. Chemical composition	: 92.1% hydrogen, 7.8% helium, then oxygen, carbon, nitrogen and neon
viii. Diameter	: 1392,000 km
ix. Circumference	: 4,373,000 km approximately
x. Rotation	: about 25 days at equator to 36 days near poles
xi. Temperature at core	: 15 million $^{\circ}$ C
xii. Temperature at the surface	: 5,500 $^{\circ}$ C
xiii. Absolute visual magnitude.	: +4.84
xiv. Apparent visual magnitude	: -26.74
xv. Mean density	: $1409 \times 10^3 \text{ kg/m}^3$
xvi. Magnetic field, average	: 1-2 Gauss
During sun spot	: 1000-4000 Gauss

(b) The sun rotates anti clockwise when seen from the north. This direction is called prograde and the clockwise direction is called retrograde. Mercury, Earth, Mars, Jupiter, Saturn and Neptune have prograde rotation. But Venus, Uranus and Pluto are retrograde. Remember one day on Venus is larger than one year because one Venusian day is 243.0 terrestrial days. The sun has great mass but it contributes little to the angular momentum.

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The whole solar system revolves around a barycenter which can be as far as 1.5×10^6 km from the center of the sun. The total angular momentum is $3.1643 \times 10^{43} \text{ kg m}^2 \text{s}^{-1}$.

The solar system [See Figure 4.1] was created from the debris of supernova explosion, blasting out of a



Figure 4.1

spinning mass of gas and dust. This hot cloud of debris pulled out into the sun and the leftovers spun around in a disc from which the planets were formed. The sun contained the original elements present in the supernova like those elements heavier than uranium, from plutonium to californium and beyond. Also other elements like aluminium, iron, chlorine etc. were also present. Most of them decayed into stable isotopes, through radioactivity. This decay process produced heat and sun became so hot. The sun is made of different layers. The surface layer is called photosphere. Surrounding the photosphere there is an unseen layer of gas called the chromosphere. The layer of gas just above is called Corona.

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FORMATION OF THE PLANETS

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The planets and other bodies were formed about 4700 million years ago from the material left over from the sun's birth. The sun was surrounded by a rotating gas consisting of hydrogen and helium and dust made up of iron, rock and snow called the solar nebula. The dust came together to form planetesimals, which joined together and formed four planets Mercury, Venus, Earth and Mars. The dust and snow farther out combined with the gases to produce Jupiter, Saturn, Uranus and Neptune. Pluto is a leftover planetesimal.

The sequence involved in the formation of planets follows. The cloud of gas produced during the initial explosion had a very small resultant angular momentum. Then the cloud started collapsing, thereby increasing the angular velocity and this collapse produced the early sun and a planetary ring, which contained H, He, the other element, molecules and solid matter. The solid matter consists of frozen gases like ammonia, methane, water etc. and iron-magnesium silicates. The temperature and pressure in the planetary ring decided the nature of minerals formed in the planet. The material in the planetary ring crystallized into minerals like olivine consisting of iron-magnesium silicate, pyroxenes made of dark silicate minerals containing iron, calcium and magnesium and kamacite, taenite containing iron and nickel. During the collapse of the cloud, gravitational energy was converted into heat energy. Part of this energy was radiated away and the remaining part increased the temperature of the sun. The radiation given out by the sun ionized the gases in the planetary ring. The sun's magnetic field increased the angular velocity of the

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ionized gases around the sun. The angular velocity of the sun decreased to conserve angular momentum of Sun which was reduced to 3.1% of the total angular momentum. Under this condition the solar ring broke down into ten concentric rings. According to Titus-Bode law these rings were placed at specific distances from the sun. If 'r' is the distance from the sun then, $r=0.4 + 0.3 \times 2^n$. For Mercury $n=-\infty$, for Venus $n=0$ and for planets from Earth to Pluto including asteroids the value of 'n' was from $n=1$ to 8. The distances predicted were later found to be correct except for Neptune and Pluto. The strong radiation given out by the sun raised the temperature of the planetary ring system.

According to Harold Urey, the water, methane and ammonia liquefied and stuck together to form mudballs called planetesimals. During this stage of the sun called the T Tauri stage the sun ejected out large masses of gas. This strong radiation from the sun blew away all the gases which were not trapped inside the planetesimals, from the inner ring to the outer rings. After millions of years the mass increased, correspondingly the gravitational field increased and the four inner rings formed, the four planets Mercury, Venus, Earth and Mars. The five outer rings formed the outer planets Jupiter, Saturn, Uranus, Neptune and Pluto. The radioactive isotopes like ^{26}Al , ^{36}Cl , ^{60}Fe were trapped inside the planets because the planet formation was so rapid that those isotopes did not get sufficient time to decay; for example the half life of ^{60}Fe was about 1490000 years. Thus the newly formed planets contained a mixture of silicates, trapped gases and metals, with the center of planets much cold. During the young age the planets

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were plastic and in liquid form and so the metals heavier than silicates began to sink to the center of the planet.⁴⁷ The silicates floated on the top. This increased the temperature and gases were forced out of the planet which formed the atmosphere. Thus the atmosphere contained gases like hydrogen, helium methane, water, nitrogen, ammonia etc. Very soon the planets like Mercury and also the Moon lost all their gases due to their relatively small gravitational fields and their surface were modified due to planetesimals bombardment. At the same time Venus and Earth retained most of the gases due to their strong gravitational fields. Mars retained the atmosphere for a longer period than Mercury or Moon, but later major part was lost. Planets like Jupiter, Uranus and Neptune retained the light gases and they have thick atmosphere containing hydrogen and helium. The outermost planet Pluto has polar caps of solid methane.

COMETS

Beyond Pluto's orbit are the leftovers of the cloud that formed the solar system. It contains billions of icy lumps and rock and are called comets. The planetesimals outside the solar system could not form planets as they were separated by a large distance. Their orbits were perturbed by the stars close to them and 50% of them orbiting in the same direction as the planets and the remaining in the opposite direction. Billions of them form a cloud called Oort cloud. About 900 comets are known. 150 have prograde motion and are called short-period comets, because of their short period, which is less than 200 years. Halley's comet is an example which was first seen in 239BC, later it was seen in 1066, 1145, 1222,

⁴⁸ 1301, 1378, 1456, 1531, 1607 and 1682. This comet appeared recently in 1986 and next is going to appear in 2061.

Edmond Halley worked in many areas of astronomical research. But he is best known for his works on comets. He was the first to show that some comets follow orbits [See Figure 4.2] which keep returning them to the vicinity

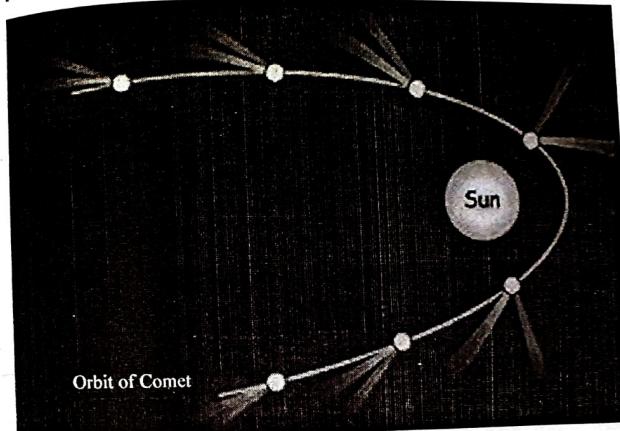


Figure 4.2

of the sun. The word comet is derived from the Latin word cometa which means long haired (some says it is from a Greek word kome means hair). It consist of two parts; a nucleus and a coma. The nucleus is the source of all masses. The coma could be larger than the sun. In addition to the nucleus and coma, a comet has one or two tails. The tail of the comet can be up to 300 million km long. Comets are identified from their periods. There are short period comets like Encke with a period of

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500,000 years. Comets are like large dirty snowballs, made up of rock and dust held together by ice and frozen gas. They originate from distant regions of solar system beyond Pluto. From the outer reaches, the gravity of a passing star nudges a comet into the inner solar system, leaving it in elliptical orbit around the sun. X

In 1949 Fred Whipple predicted that the comets are giant dirty snowballs. In 1986 a space probe called Giotto flew past the nucleus of Comet Halley. The photographs received from the probe revealed that the nucleus of the Comet is an icy, rocky, potato of dimension 16×8 km. The nucleus consist of chunk of dust and frozen ice of compounds like methane, ammonia, water and carbon dioxide.

When a comet comes closer to sun it starts to shed material. The comet Halley is supposed to make 2300 more trips around the sun before it gets decayed completely. When the comet comes close to the sun, the surface snow is turned into a head of gas called coma. The sun's radiation sweeps this into a gas tail. The dust particles are also swept back to form a dust tail. When sunlight passes through the cloud of dust and gas produced from the vaporization of ice, it lights it up enveloping the comet in a fuzzy glow. The sun creates a breeze, the solar wind which blows the fuzzy cloud in a kind of slipstream behind the comet, which appears as a luminous tail, and it never faces towards the sun.

When the cometary light was analysed it was seen that the comas contained nonmetals like HNC, NH₃, H₂O etc. and the tails contained Ca⁺, OH⁺, CN⁺ etc. These atoms and molecules represent the earliest composition

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4.10 of the solar system. When earth crosses one of the cometary trails, particles are captured and they burn. The result is a bright streak of light in the sky. This is called meteor or shooting stars [See Figure 4.3]. They



Figure 4.3

are about the size of a grain of sand and an estimated hundred million a day zip through the thin air with a speed of 209200 km/hr. The comets and asteroids collide with Earth. The nucleus of a small comet enter the Earth's atmosphere at a speed of 30-40 km/s. The cometary body was about 50m across and had a mass of 60,000 tons. Its kinetic energy was equivalent to 704 times the energy of the 12.5 kilotonne of atom bomb. 700,000 years ago there was a cometary impact, in the south of Australia. The molten rock produced splashed to Philippines and Vietnam. The molten fragments smaller in size were solidified and are called tektites. They are fused rock and are glasses which have no crystalline structure. A

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meteorite having weight greater than 50,000 tonnes formed a crater called Wolfe creek crater in western Australia. Similar crater were created in Ghana, 1.3×10^6 years ago and in Texas, 3.5×10^7 years ago

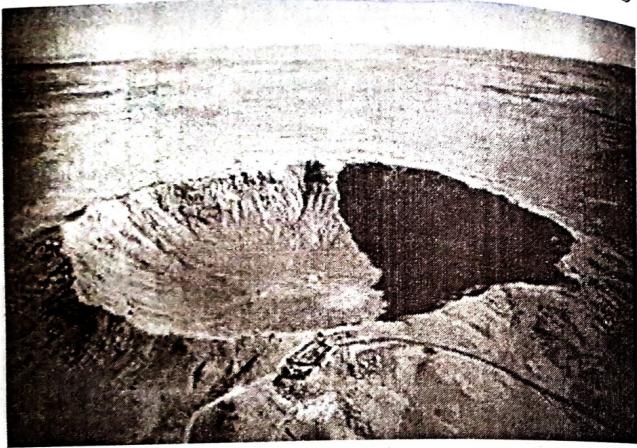


Figure 4.4

[See Figure 4.4]. About one tonne of meteorites hits the earth everyday. Carolyn, Eugene Shoemaker and David Levy together found 32 comets and 1125 asteroids. Shoemaker-Levy 9 is the most famous among them. It is not a single comet, but a string of mini comets. It was not orbiting Sun but Jupiter. On May 22, 1993 the astronomy community predicted that this comet is going to hit Jupiter, after 14 months. Shoemaker-Levy 9 comet was orbiting Jupiter since 1914. On July 7, it passed within 90,000 kilometers of Jupiter. It was broken into pieces. Around 22 fragment of comet plunged into the upper atmosphere of Jupiter between July 16 and 22. Their prediction was correct. 60 million years ago a meteor or a comet collided with Earth, causing the extinction of dinosaurs from Earth. The impact produced

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energy equivalent to 100 million hydrogen bomb about 50,000 cubic km of rock were blasted into the atmosphere in the form of dust, gas and droplets of molten rock, causing wild fire around the world. Acid rain devastated even plant life. The end of the world. That was Earth's history. History can be repeated- some predicts it to happen this year.

PLANETS AND SATELLITES

The word planet comes from a Greek word which means wanderer. It is called so because when planets are seen from the Earth the planets move across the sky in an erratic way. There are eight planets excluding Pluto. It was discovered in 1930. It has an erratic orbit that at times bring it inside the orbit of Neptune. About 5 billion years ago Sun was surrounded by a swirling disc of dust and gas. The heavier elements were attracted together to form the inner terrestrial planets-Mercury, Venus, Earth and Mars. Lighter elements like hydrogen and helium were swept into outer gaseous giants Jupiter,

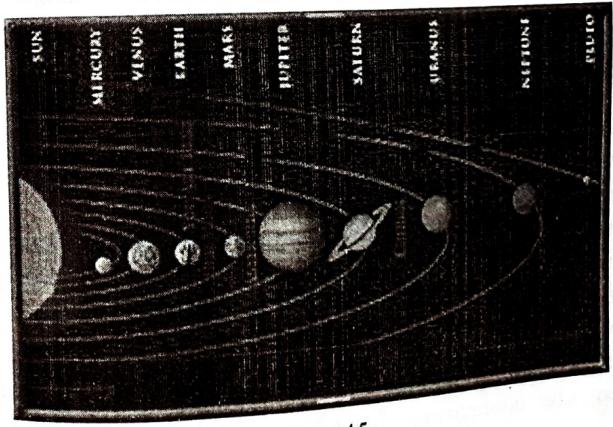


Figure 4.5

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Saturn, Uranus and Neptune. On the outer edge of the solar system is Pluto which is an asteroid caught in the orbit of Sun. Planetary discovery beyond our solar system has become a regular phenomenon, since 1996. The way in which they are found reveals that the new planetary system differ considerably from the system we live in (Figure 4.5).

Planets are divided into two categories, (i) The inner or terrestrial planets and (ii) the Jovian planets. The inner planets are small and have density 4 to 5 gm/cc and the outer planets have a mean density 1 to 2 gm/cm³. The terrestrial planets Mercury, Venus, Earth and Mars have no rings. Mercury and Venus have no moon, Earth has one moon, Mars has two (Phobos and Deimos). The two small moons of Mars are captured asteroids, the Earth-Moon system is unique among the terrestrial planets. Jupiter has 28 moons, Saturn has 30, Uranus has 20 and Neptune has 8 moons. In addition to the satellite systems, the Jovian planets possess rings.

The celestial bodies in general move in elliptical orbits. Suppose a body is projected with a velocity $v = \sqrt{rg}$ where r is the radius of the earth, depending on the velocity, the orbit can be circular or elliptical. For the lowest possible velocity the orbit is circular. For still greater velocity the orbit is elliptical. If the velocity is equal to the escape velocity then the orbit will become parabola. If the velocity is still greater, the orbit will be a hyperbola. The escape velocity is $v_e = \sqrt{2rg}$. The motion of the planets are governed by Kepler's laws. By adding the angular momentum of the sun and the planets, we get the total angular momentum of the system. It is directed along

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^{4.14} the rotational axis of the sun. The plane normal to the angular momentum vector is called the invariable plane. The orbital planes of the planets are inclined to the invariable plane, which is resulted from the gravitational interaction with some passing celestial body, inside the solar system. Orbital plane of earth is inclined at an angle of 1°39'. The axis of Uranus coincide with the invariable plane.

Mercury is the closest planet to the sun. Its surface is scarred pitted by meteorite impact. It has almost no atmosphere. So it is freezing at night and is scorched during the day. Name of the innermost orbit is given the Roman name for the Greek god Hermes. The diameter at the equator is 4878km and the period of orbit around the sun is 87.97 days. Its spin period is 175.94 days. Helium, oxygen, hydrogen are found in Mercury, in very small amount.

Mercury is difficult to see because of the Sun's glare. But **Venus** is easy to see. After the sun and moon, Venus is the brightest object. Just like Moon, it goes through a cycle of phases, from the slim crescent to a full disc. The first person to observe this circle was Galileo Galilei. Just like Earth, Venus underwent a molten period when dense material sank to the center. Its molten iron-nickel core is surrounded by a rock mantle which supports the rock crust. It is completely choked by a thick, dense atmosphere. Upper cloud layers rotate every four days. The rocky surface of Venus is marked by volcanoes, rifts and solidified lava flows. The atmosphere contain carbon dioxide. Diameter at the equator is 12104 km. Mass of Venus is 0.815 times that of the Earth. The period of

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orbit around the sun is 224.7 days. The spin period is ^{4.15} 243 days 3 hours and 50 minutes.

The temperature of the surface is 480° C. About 20 spacecraft have investigated Venus. Venus has a surface of hot desert, with a small amount of lowland and highland. The atmosphere also contains thick yellow-white clouds of sulphuric acid gases. The atmosphere works like a greenhouse, trapping the sun's energy. The surface pressure is 100 times that of the Earth. The planet got its name from Greek goddess of love, Aphrodite. Venus sky is red because CO_2 scatters red light. The gases found in the order of decreasing abundance are H, He, CH_4 , H_2O , N_2 , NH_3 and H_2S . Both Earth and Venus lost H and He and retain other gases. In a process called photolysis, ultraviolet breakup molecules of H_2O , NH_3 and H_2S into free oxygen, free nitrogen and sulfur. Thus the atmosphere consists of CO_2 , small amount of nitrogen SO_2 and water vapour. There is no liquid water on Venus and there is no life. Since the rotation of Venus is slower than its revolution the atmospheric circulation on Venus is entirely different from that on the Earth. The air flow direction is same as that of the planet from east to west. At the bottom of the cloud layer the wind speed is 350 km/hr and it decreases steadily to 3.5 km/hr near the ground. Since there is haze below and above, the clouds conceal the solid surface of Venus. American and Russian spacecraft have studied the topography of Venus. There are scattered depressions of depths 2km below the mean radius of the planet. There are lowlands covering about 30% of the surface of the planet and rolling uplands of average height 2.5 km and covering 60% of the surface. Remaining 10% of the surface is high plateaus at an

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^{4.16} average altitude of 4 km. Above the plateaus, there are mountains of height 12km above the mean radius of the planet. The spacecraft Magellan has revealed the existence of volcanic and tectonic features on the surface of Mars.

Earth is the only planet which is geologically active. It is unique in the solar system in having liquid water. Also it is the only planet which support life. Earth has features that are not found anywhere else in the solar system. The real name of Earth is Gea, wife of Uranus and mother of Zeus. The young Earth was formed with the other solar system planets about 4,000 million years ago. Initially it was cold, it got heated due to radioactivity. The heavy iron sank to the center and the lighter rocks floated on the top. At present Earth's iron core is surrounded by a fluid mantel of rock. The process of photolysis is less efficient than on Venus, because Earth receives half as much radiation from the sun as does Venus. Still CO_2 and SO_2 collected in the Earth's atmosphere. The temperature rose due to increase in the amount of CO_2 , the sky turned red and the Sun turned bluish. Since the temperature of Earth was low CO_2 dissolved in liquid water and precipitated as carbonate. In a few million hundred years, most of the CO_2 was removed from the atmosphere, the nitrogen gas was left alone. The sky turned blue because nitrogen molecules scatter blue light. The precipitated nitrogen molecules are now found in the living and fossil coral reefs of the world. Compared to Venus, Earth has a thin atmosphere. It is thin enough to let sunlight to pass through, but thick enough to prevent the way of other forms of harmful radiation like ultraviolet from the sun.

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The atmosphere also slows down and vaporizes tiny space rocks called meteoroids.

About 500 million years ago Earth was just like a landscape covered in ash from countless volcanic eruptions. There was more mud than water and sulphurous pools. Nothing in this terraine could support life. Life evolved in water slowly and ocean supported varied plant and animal form. Plant life was concentrated in shallow costal waters where it could absorb sun's energy- Algae began to adapt to life out of water. Another 100 million years passed, plants appeared on land, most were leafless and height less than a few millimeter. This marked the greening of the land. Plants started absorbing carbon dioxide from the atmosphere and emitting oxygen. Then came the sea creatures followed by animals living on dry land. Without plants there would be no food and only small amount of breathable oxygen. The first born animals were fed on vegetation. Then came carnivores, spider-like creatures, scorpions and centipedes. Thus life came into Earth. The orbital period of Earth is 365.25 days and spin period is 23 hours 56 minutes. The diameter at the equator is 12104 km. Earth has one natural satellite- the Moon.

There are different stories regarding the formation of Moon. It may have broken off from Earth or formed from the material around young Earth. Another big splash theory is that a Mars sized body collided with the young Earth. Moon is formed from the debris. Another theory is that about 4.6 million ago the debris from a collision between the Earth and a passing asteroid fused together to form Moon, yet a few other say that Moon is a piece of

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Mercury's mantle, which escaped from Mercury and later captured by the Earth. The average distance from the Earth is 384400 km. Time to orbit Earth is 27.32 days, which is the same as time taken to spin once on its axis. Its average diameter is 3476.6 km. Moons gravity exerts a strong influence on the Earth, causing tides and over millions of years slowing the spin of the Earth, lengthening the day. The Moon is not tectonically active. There is no volcanoes nor violent earthquakes, only occasional tremor. There is no snow or wind to erode the landscape. The surface features of the Moon are due to the impact of meteorite. Two main landscape areas are identified, the cratered older highlands and the younger maria or 'seas'. Medieval astronomers described the smooth dark areas visible on the Moon's surface as seas. Later they were given some romantic name like Mare Tranquillitatis or sea of Tranquility. Moon has no light of its own. The Moon is the brightest object in the sky because it reflects sunlight. When Moon travels around the Earth we can see different amounts of its sunlight face ranging from a thin crescent to a full face. When the side of the Moon facing us has no sunlit on it we cannot see it. This called New Moon. The Earth and the Moon are kept in synchronise rotation due to the gravitational force between them. This means, the time the Moon takes to spin once on its axis is the same as it takes to orbit the Earth, so the same side of the Moon always faces us. The far or dark side was a mystery till october 1959, when the Soviet spacecraft Luna 3 sent back images of it. Around 2000 samples of Moon rock have been collected and brought to Earth. Analysis shows that there are different types of rock in Moon. They are

classified into two categories, basaltic volcanic rocks associated with the maria and aluminium and calcium rich rocks, relics of the Moon's earlier history. Recent probes have revealed that there is a frozen water at the Moon's pole. Since there is no thermal protection its surface temperature varies from 125°C at Lunar noon to -160°C during night. The density of the Moon is only 3.3 gm/cm^3 . The formation of rocks ended about 3 billion years ago. After that the only activities in Moon are internal rock adjustments called Moonquakes which were detected by the instruments left on Moon by the Apollo astronauts. The orbit of Moon is inclined at 18.3° to 28.6° to the equatorial plane of the Earth. This high inclination rules out the possibility that the Moon is formed from the Earth. Another supporting evidence for this is that these rocks contain no water and no minerals with OH group. So it is believed that Moon is a part of Mercury. It is now known that the Moon is moving away from the Earth at a rate of about 4cm per year.

Mars is the fourth planet and it is a vast desert. The brightest red star in the Earth's sky is Mars. The most distinctive feature of Mars is its red colour, it comes from rock and dust covering its surface. In 1976 Viking spacecraft analysed the soil and found it to be iron-rich. Mars was given the name of the Greek God of war, because of its colour. Its mass is 11% of that of the Earth. Diameter of equator is 6794 km. Period of orbit around the sun is 687 days and its spin period is 24 hours and 37 minutes. The average temperature is -63°C . Mars has two natural satellites by name Phobos and Deimos. The atmosphere contains mainly CO_2 with some nitrogen and oxygen. It has two ice caps, over its poles. The ice cap is made of

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ice, water and a seasonal, thin layer of frozen CO_2 . During summer it vaporizes and condenses over the opposite pole, where it will be winter. The atmosphere of Mars is very thin, so its surface can be clearly seen. According to Giovanni Schiaparelli, an Italian astronomer the Mars was criss-crossed with straight lines called Canali. Percival Lowell thought these lines to be the work of Martians. On July 14, 1965 when Mariner4 visited Mars, the photographs sent revealed that there were no canals but were only impact craters. There is difference between northern and southern hemispheres. The northern hemisphere is a lowland, sparsely cratered. The southern hemisphere is a heavily cratered highland at an average height of 2 km above the mean radius of the planet. There are huge volcano structures in the northern hemisphere. The giant volcano Olympus Mons is not only the largest mountain in Mars, but in the whole solar system. At 700 km across and 27 km high it is around 3 times as high as Mount Everest on Earth. The windstorms in Mars are capable of raising dust. At certain times the wind speeds increase to over 100 km/hr blowing up a dusty storm which lasts for months. The dust makes the sky appear pink or red, so it is called red planet. The two tiny Moons orbit around the Mars. They are members of asteroid belt captured by Mars. Both have craters, but Phobos is covered in grooves. They are just 20km across. Mars can be changed into a planet like Earth, first make the ice melt. Then introduce plants which would produce oxygen. After certain time the planet would be able to support animal life. The whole process will take tens of thousand years and the cost.....?

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Jupiter is the largest planet. It contains three times more mass than the other eight planets put together. It consist of gases and liquids, with a fairly small rocky core. The planet shines brightly in Earth's night sky because the thick cloud at the top of its atmosphere reflect sunlight well. Jupiter is the Latin name for Zeus, the ruler among the twelve Olympian Gods. The core of Jupiter is surrounded by an ocean of hydrogen in metallic and liquid form. There is vast atmosphere of hydrogen and helium above the core, which is eight times thicker than Earth's. The core is at $35,000^{\circ}\text{C}$ while the upper cloud layers are at -140°C . The atmosphere Jupiter contains thick layer of methane and ethane about 1280 km height as well as hydrogen and helium. The Galileo space probe found less water and very strong winds deep in atmosphere. Jupiter has 28 moons, out of which the main moons are Io, Europa and Ganymede. The core of Jupiter has silicate and metals at its center. Jupiter has a dipole magnetic field and is inclined about 10.8° to the rotational axis, but its direction is opposite to that of the earth. This field arises from the convection motions in the hydrogen mantle. The dipole moment is 20,000 times greater than that of the Earth, but at the equator it is only 10 times greater. The wind flows alternately eastward and westward. Jupiter's Great Red Spot is a large oval vortex consisting of a mass of warm gases rising 8 km above the clouds. The red colour is due to organic molecules, amino acids synthesized by electrical discharges. The spin period of Jupiter is only 9 hours and 55.5 minutes. So the atmosphere is controlled by Coriolis effect. Jupiter radiates more energy than it receives from the sun. The distance of the satellite vary from 56,500

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^{4.21} km to 24×10^6 km. Jupiter also has a system of three tenuous rings which extend from 30,000 km to 140,000 km. The innermost ring is about 20,000 km thick and the outermost 4,000 km. The middle one is very thin. The ring is made of cemetery particles or particles in shooting star. The innermost four satellites are called shepherd satellites and the next four satellites are called Galilean satellites. The names of the satellites in the order of increasing distance are Io, (son of Apollo and the daughter of an Athenian king), Europa (daughter of the king of Sidon) Ganymede (lover of Zeus) and Callisto (girlfriend of the hunting goddess Diana). The satellites Io and Europa is mainly made up of silicates. The surface of Io is covered with sulfur compounds. The surface of Europa is an ice crust. The density of Ganymede and Callisto is still lower, about 1.94 gm/cm^3 and 1.86 gm/cm^3 . Each consists of silicates and solid ice. The first few satellites have prograde orbits whereas the next four has retrograde orbits. They all have different angle of inclination. Io is a little bigger than Earth's moon. It is one of the most remarkable bodies in the solar system. It is among the largest of Jupiter's family of moons.

Saturn is the jewel of the solar system. It is the sixth planet from the sun and is almost twice as far away as its neighbor Jupiter. It is a gas giant. It rotates as fast that its bulges in the middle and flattened at the poles. The period of orbit around the sun is 29 years and 168 days. But the spin period is only 10 hours and 40 minutes. The average temperature is -180°C . There are 30 moons. Titan is the name of the main moon. Diameter at its equator is 119,900 km. Saturn is named after the Roman God of fertility and agriculture. It has a mass of 95 times

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that of the Earth. Its structure is similar to Jupiter. It has a dipole moment which is 20 times weaker than that of Jupiter. The direction of magnetic field is along the direction of rotational axis and point northwards. Above the mantle there is 1000 km thick atmosphere. It consists of 82% of molecular hydrogen, 17% helium and 1% of other gases. The top wind speed is 1800 km/hr. Saturn radiates more energy than it receives from the sun. Out of the 30 moons, the largest one, Titan has a diameter of 5150km and density 1.88g/cm^3 . Titan contains rock and surrounded by mantel of ice. It has 1km thick ocean of liquid ethane, methane and nitrogen. Atmosphere pressure is 15 atmosphere. A few other satellites have densities between 1.2 g/cm^3 and 1.4 g/cm^3 . They consist a mixture of water ice and rock. The outermost satellite has a retrograde orbit inclined at 175° . The rings of Saturn were first noticed by Galileo. There are seven concentric rings separated by gaps ranging from 7,000km to 420,000 km. The rings consist of ice particles coated with dust of different sizes. The first ten satellites lie within the ring. Comet which passes very close to Saturn were disrupted and captured and thus the rings are produced. It is also possible that the material in the rings are part of Saturn which fail to aggregate into satellite because it was inside Roche limit where the tidal force was stronger than the self gravitational force of the satellite. Even though Saturn has 95 times mass of the Earth, the average density is very low that it is the only planet lighter than the same volume of water. This means if Saturn is put in a big bucket of water it will simply float. A few of the Saturn's moon were discovered from Earth and a few others with the help of the satellite. Since Saturn spins very fast

4.23

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^{4.24} and has low density, it has a bulging equator. Saturn's tummy bulges more than any other in the solar system. The prize for the planet with maximum number of moons goes to Saurn.

Until 1781, it was believed that there was no planet after Saturn. But a space probe called Voyager 2 discovered it. **Uranus** is twice as far from the sun as Saturn. Its discovery doubled the size of the solar system at a stroke. Uranus is named after the Greek God of the sky. Uranus has 20 moons and 11 rings. The period of orbit around sun is 83 years and 273 days. The spin period is 17 hours and 14 minutes. Its average temperature is -214°C . The names of the main moons are Titania and Oberon. It has a rocky core which makes up about one-quarter of the planet's mass. Above this there is a layer of water, ammonia and methane in ice and liquid form. The outer layer is made up of hydrogen and helium gases. The magnetic axes is at 55° to the rotational axis.

The angular momentum vector of Uranus is 8° south of it. When seen from north, Uranus rotation is retrograde. A giant impact might have caused the tilt. The polar summer or winter lasts about 20 years. The air circulation is affected by Coriolis force. Uranus emits the same amount of energy as it receives from the sun. Uranus appears as fuzzy blue-green ball of gas. Methane in its atmosphere reflects blue and green sunlight. The planet receives about 370 times less sunlight than Earth, and hence the temperature is -209°C . Five of Uranus's moon were discovered from the Earth. The smaller moons were revealed by Voyager 2's cameras in 1986. The farthest moon is called Oberon. It revolves around Uranus at a distance of 582,600km. The moons of Uranus are

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dark bodies of rock and ice. Titania is the largest. Craters and valleys cover its surface. The 11 rings of Uranus extend from 12,500km to 25,000km from the equator of the planet. Except two satellites all others are outside the ring system. The satellite Miranda has an inclination of 3.4° . All others have an inclination less than half a degree.

Neptune is the most distant gas giant. It is so far away that very powerful telescopes are needed to watch them. Details of Neptune were revealed when Voyager 2 flew nearby in 1989. Neptune got its name from the Roman name for Poseidon, the Greek god of sea. It has a methane rich atmosphere that becomes liquid and then metallic towards the centre. It has an almost circular orbit. There are 8 satellites and a few faint rings. Mass of Neptune is 172 times that of the Earth. The orbital period around the sun is 164 years and 292 days. The average temperature is -220°C . The name of the main moon is Triton. The rocky core is surrounded by an ocean of water, ammonia and methane. The atmosphere is made of hydrogen, helium and methane. The blue colour of Neptune arises from the methane gas. The images received from Voyager revealed that Neptune is a blue planet, flicked with white clouds of methane ice crystals. In the southern hemisphere there is a region known as the Great Dark Spot which is a huge storm that rotates around the planet. The speed of wind in Neptune is 2160km/hr. Two moons were discovered from Earth, Triton and Nereid. Six were discovered by Voyager 2. Triton has two very different hemispheres. The south pole has active volcanoes. It has a pink cap of nitrogen and methane ice. The north pole has many shallow valleys

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^{4.25}
and bluish in colour. Neptune's axis has an inclination of 29.6° , with respect to the normal to the orbital plane. The ring system of Neptune extended from 17,000 km to 38,000 km from the equator of the planet. There are four inner satellites within the rings and remaining outside. It is said that the satellite Triton and Nereid were formed somewhere else and they were captured by Neptune. Neptune was first noticed by Galileo in 1612. But he failed to recognize it as a newcomer. Perhaps because he feared trouble in the church, he failed to follow up his discovery.

^{4.26}
Pluto is a frozen world. Pluto is the only planet which has not been investigated by a spacecraft. It got its name from the Roman God of underworld, Hades who is also the God of wealth. Pluto was discovered by Clyde W Tombaugh, an American amateur astronomer in 1930. Pluto has an orbit with a high inclination on the plane of the ecliptic and a high eccentricity. Pluto is the smallest in the solar system. The surface of Pluto is a solid landscape of frozen methane and the atmosphere is very thin. Pluto has an erratic orbit. Mass of Pluto is only 0.002 times that of Earth. The orbital period is 248 years and 197 days. Spin period is 6 days and 9 hours. The average temperature is -230°C . Pluto is forty times farther from sun than the Earth, so it is dark. The orbit of Pluto is so eccentric that the distance of the planet from the sun at perihelion is 60% of at aphelion. The orbit is more elongated than that of any other planet. Pluto moves closer to the sun than Neptune, so that for a time Neptune is the most distant planet in the solar system. The satellite of Pluto is called Charon. It is the largest satellite in the solar system. It has a synchronous orbit around Pluto, in its equatorial plane. Pluto and Charon composition is the same. Now Pluto is no more considered as a planet.

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ASTEROIDS

According to Copernicus and Kepler something was missing between the orbits of mass and Jupiter. They thought there was a hole in the solar system. Giuseppe Piazzi was an Italian astronomer. He spent most of his time industriously compiling the catalogue of 6748 bright stars. On the evening of 1 January 1801 Piazzi noted a new faint star. First he thought that it was comet. But his calculations showed that its orbit was circular. So he thought it was a planet. He named it as Ceres. But it was very dim and small very soon it was identified as a new species of celestial body called asteroid. Thus apart from the proper planets, we have a few million minor planets called asteroids. They are different sized rock; ranging from specks of dust to some which are a few hundred kilometers across. Most of them travel in orbit between Mars and Jupiter and is called asteroid belt. Others follow different orbits. Asteroids are materials that failed to form a planet due to the gravitational pull of the Jupiter. Most asteroids orbit around the sun in the asteroids belt. Others are in smaller groups with different orbits. A group called the Trojans travel along the Jupiter's path, some in front of the planet and some behind. Another group called Apollo family have orbits that cross the path of Earth. An asteroid called Chiron orbits between Saturn and Uranus till 1991 the asteroids had been studied mainly from Earth. The Galileo space probe observed an asteroid called Gasparo lying on the edge of the asteroid belt. It is a small irregular shaped asteroid 12 km across, which rotates once every seven hours. The larger asteroids are spherical or spheroids in

4.27

shape but the smaller ones are shaped like irregular potatoes. [Figure 4.6].

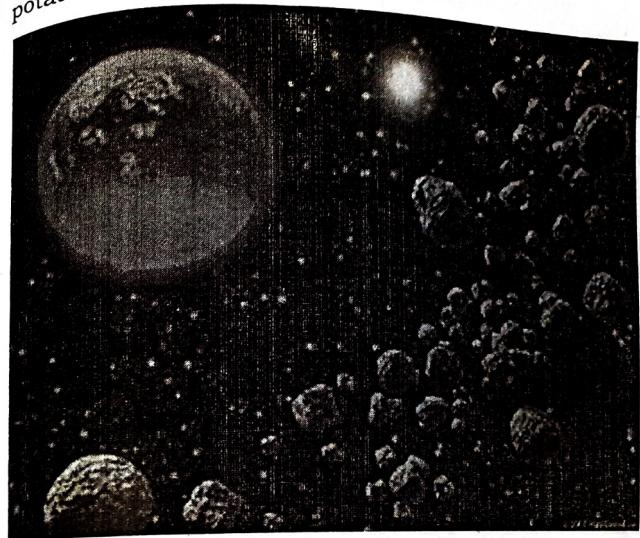


Figure 4.6

Asteroid's size is calculated by studying its brightness, by timing it as it crosses a background star. It can also be done by direct measurement if it comes close to Earth. There are seven asteroids with diameter greater than 300 km, 200 having diameter greater than 100 km, another 2000 with diameter greater than 10 km. There are around 500,000 asteroids whose diameter is greater than 1 km. The asteroids are gray in colour. They consists of iron-magnesium silicates. About 15% consists of iron-magnesium silicates plus iron-nickel metal.

Ten largest asteroids with their diameter are shown in table.

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Name	Diameter Km
Ceres	940 km
Pallas	580 km
Vesta	576 km
Hygeia	430 km
Interamina	338 km
Juno	288 km
Psyche	248 km
Thule	130 km
Astraal	120 km
feronia	96 km

About 5% are similar to iron meteorites and remaining 5% represent other types of meteorites. The total mass of asteroids is about 2% of the mass of moon. The asteroids are distributed in a belt of mean width 2.4 A.U. in concentric rings separated by gaps called Kirkwood gaps. The gaps arise due to the absence of asteroids with certain fractions. $\frac{1}{4}$, $\frac{1}{3}$, $\frac{2}{3}$, etc. of the orbital period of Jupiter.

There are around 1000-2000 asteroids in the Amor group whose orbits have a perihelion between the orbits of moon and Earth. They can collide with Earth and the rate of collision is 0.5 per million years. The Apollo group contains asteroids whose perihelion is inside the Earth's orbit, with a rate of collision 2 per million years. These asteroids have prograde orbits, having inclination less than 20° with respect to the plane of the ecliptic. 65 million years ago an asteroid having a diameter of 10 km struck Earth. A dark cloud, dust and smoke covered the

4.30 Earth. Group of plants and animals including dinosaurs died. In future also there is chance of hitting. Small asteroids hitting Earth are called meteorites [See Figure 4.7].



Figure 4.7

METEORITES

Any old lumps of interplanetary rock, say from asteroids or from the surface of the planet, large enough to survive the journey through Earth's atmosphere are called meteorites. There are three strong meteorites which are rocky with small amounts of iron and nickel. Most



Figure 4.8

4.31
meteorites are this type [See Figure 4.8]. Iron meteorites are mainly iron and nickel. They are thought to originate in the cores of the asteroids. About 5.7% of the meteorite are of this type. The largest known meteorites belong to this category the stony -iron meteorites consists of mixtures of silicates and metals with some iron sulfide and iron -nickel phosphide. The stony meteorites are again divided into chondrites which contain minute spherical bodies consisting of olivine, pyroxene called chondrules and achondrites, which contains no chondrules. The carbonaceous chondrites represent the earliest most primitive planetary matter.

Each year on an average 550 meteorites fall on Earth. About 1700 meteorites have been recovered. Heaviest meteorites were found at different parts of the world. The details are as shown in table 2.

TABLE-2 HEAVIEST METEORITES

Name of place	Weight of meteorites
Hoba west, Namibia	60 tonnes
Ahnighito, West green land	34 tonnes
Bacuerito, Mexico	27 tonnes.
Mbusi, Tanzania	26 tonnes
Agpalik, Greenland	21 tonnes
Armanty, Outer Mongolia	20 tonnes

When meteorites fall on Earth they are destroyed on impact .But large meteorites leave behind a crater .The size of craters the place and year are given in the Table-3.

Table-3

Name	Year of discovering	Diameter metre
Meteor crater, Arizona, USA	1871	1256 m
Wolf creek, Australia	1947	675 m
Boxhole, Australia	1937	175 m
Odessa, Texas USA	1921	170 m
Oesal, Estonia	1927	100 m

The smallest size of the meteorites are of centimeter size which can survive entry through the atmosphere, they shed molten droplets which get solidified and accumulated on Earth as metallic or silicate spherules called cosmic spherules, whose size range from 0.10 mm to 1 mm. There are meteorites which are basaltic in composition, derived from Moon, Mars and ancient planetoid or asteroid. The Meteorites came from the mutual collision of two or more early planetoids in the asteroid belt. About one tonne of meteorites hits the Earth every day. The speed of the meteorites falling through the atmosphere is about 32-95 km/s. A meteorites weighing over 50,000 tonnes formed a crater having a diameter 675m in western Australia. The Barringer meteorites landed in Arizona, United States produced a crater 1.3 km across. So far no person is known to have killed by ameteorite fall.

MODEL QUESTIONS**SECTION A****BUNCH I****OBJECTIVE QUESTIONS**

1. The Sun makes a ___ times energy than all nine planets.
 a) One million b) 10 million
 c) Hundred million d) Fifty million
2. The name given to sun by Greeks is
 a) Ra b) Helios
 c) Apollo d) Adithyan
3. The surface gravity of Sun is ___ times that of the Earth.
 a) 6 b) 10
 c) 50 d) 38
4. The solar system was created from the debris of
 a) Big bang b) black hole
 c) asteroid d) supernova
5. The surface layer of sun is called,
 a) Photosphere b) chromosphere
 c) Ionosphere d) Corona
6. Earth and Venus retained most of the gases due to ___ forces
 a) Magnetic b) electric
 c) electromagnetic d) gravitational
7. Halley's comet was first seen in
 a) 299 AD b) 239 AD
 c) 1066 AD d) 1066 BC
8. Comets are giant dirty balls. This was first predicted by.

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- a) Halley b) Newton
 c) Galileo d) Fred Whipple
- The largest planet in the solar system is,
 a) Mars b) Jupiter
 c) Venus d) Uranus
- The number of satellites of Saturn is
 a) 1 b) 13
 c) 16 d) 30

BUNCH II**FILL IN THE BLANKS**

1. ___ is named after the Roman God of fertility and agriculture
2. The spin period of Uranus is ___.
3. The ___ color of Neptune arises from methane gas.
4. The first asteroid was discovered by ___.
5. The asteroid group called ___ family have orbit that crosses the path of the Earth.
6. The smaller asteroids are shaped like irregular ___.
7. The largest asteroid has a diameter of ___ km.
8. Sun is an example of a ___ star.
9. The sun rotates ___ when seen from the north.
10. The planets and other bodies were formed about ___ millions of years ago.

BUNCH III**TRUE OR FALSE**

1. Sun is middle aged and will die one day.
2. The radioactivity decay process produced heat and sun became so hot.
3. A comet has many tails.

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4. The comet Eneke has a period of 33 years. 4.35
5. The two small moons of Mars are captured asteroids.
6. The Jovian planets have no rings.
7. The motion of planets are governed by Kepler's laws.
8. Mars is the closest planet to sun.
9. There is no liquid water in Venus, and hence no life.
10. Jupiter is the largest planet in the solar system.

ANSWERS

OBJECTIVE QUESTIONS

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

FILL IN THE BLANKS

- 1) Saturn 2) 17 hrs 14 mins
3) Blue 4) Giuseppe Piazzi
5) apollo 6) potatoes
7) 940km 8) G₂
9) Anti clockwise 10) 4700

TRUE OR FALSE

- TRUE → 1, 2, 5, 7, 9, 10
FALSE → 3, 4, 6, 8

SECTION B

VERY SHORT ANSWER QUESTION

- 1) Why sun is considered as God?
- 2) In sun how much matter is converted into energy?
- 3) What will happen to sun when hydrogen fuel is finished?
- 4) What is black dwarf?
- 5) Distinguish between prograde and retrograde motion?

- 4.36
1) How did sun become so hot?
2) What is corona?
3) What are the sequences involved in the formation of a planet?
4) What determines the nature of minerals formed in the planet?
5) What are planetesimals?
6) During planet formation why Mercury lost all the gases?
7) What are comets?
8) What are satellites?
9) How many moons or satellites are there for Neptune?
10) Name the different categories of planets?
11) Name the terrestrial planets?
12) What is invariable plane?
13) Write a note on the planet Mercury?
14) Write a note on the atmosphere of Venus?
15) When was Earth formed?
16) What is sea of tranquility?
17) Explain why the same side of moon always face us?
18) How did Mars got its red colour?
19) What are Canali?
20) Give the types of bodies to differentiate between stars and planets?
21) Write a note on the internal structure of Jupiter?
22) How many rings are there for Jupiter?
23) Which planet is called the jewel of solar system?
24) Write a note on the rings of Saturn?
25) How many satellite lie within the ring?
26) How many rings are there for Uranus?
27) What is Titania?
28) What is Oberon?

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- 4.37
 34) How many satellites are inside the ring system of Uranus?
 35) What is the average surface temperature of Neptune?
 36) What is great dark spot?
 37) Is Pluto a planet? Why?
 38) Write a note on the orbit of Pluto?
 39) What are asteroids?
 40) What is asteroid belt?
 41) How is asteroid size determined?
 42) How did dinosaurs disappear from Earth?
 43) What are meteoroids?

SECTION C

SHORT ANSWER QUESTIONS

- 1) Write down the number of moons of different Jovian planets?
 2) "The Earth - Moon system is unique among the terrestrial planets". Justify?
 3) Compare the equatorial diameter, mean density, mean distance from the sun and rotational periods of any three planets?
 4) Write down the largest moons of terrestrial and Jovian planets?
 5) Give the theory of production of meteoroids from asteroids?
 6) Explain some features found in comet. Why the comets are termed as dirty snow balls?
 7) Explain what happens when a comet approaches the sun?
 8) Explain the different types of meteorites based on their chemical composition?
 9) What is New Moon? Why it is called so?

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4.38
 10)

The Solar System
 Write a note on the formation of the earth and moon?

SECTION D

LONG ANSWER QUESTIONS

- a) Explain the formation of planets?
 b) Briefly describe the constituent of the atmosphere of Jovian planets?
 What are comets? How are they formed? Briefly explain the various parts of comet?
 Discuss the structure and constituent components of terrestrial planets?
 Explain the formation of Moon and its various phases?
 Describe the structure of the largest planet in our solar system. Briefly explain the details of its moon
 Describe the nature of planets having rings. Specify the position of moons with reference to the rings?
 a) What are asteroids?
 b) How are they formed?
 c) Compare asteroids and meteoroids?

- 8) Explain the significant features of Earth, Sun and Moon?

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