CHAPTER I

THE UNIVERSE AND ORIGIN OF MATTER

Introduction:

In astronomy, the measurement of distance is in fact the time light takes to travel from point A to B at a speed 300,000 km/s.

Earth-Moon distance = 1 light second;

The Earth-Sun distance = 8 light minutes;

The diameter of the sun = 20 light seconds.

The speed of light on the scale of the universe is very low, and this shows us that the information brought from the skies is old. In conclusion “looking far is looking early”.

The most distant objects in the universe are located 13.8 billion light years away (90% of the age of the universe). The main units of measurement of distances in the universe are:

The light year, a l = 9.46 1012 km

The astronomical unit (AU) = Earth – Sun distance = 150,106 km.

The parsec (PC) = The parsec (pc) is the least used unit. It measures very long distances. It is even greater than the light year because its value is approximately 3.26 al or 30,000 billion km (about 30,800,000,000,000 km) hence the interest of these units of measurement. The parsec is the distance such that an astronomical unit is seen under an angle of 1 second. 1pc = 30,857,000,000,000,000 km.

1 1 1 ARCHITECTURE OF THE UNIVERSE

1 1 1 Galaxies:

Galaxies are the main structures of the universe; they are a sort of factories for transforming gaseous matter into stars. The galaxy in which our solar system is located is known as the "Milky Way". It is in the form of a flattened disc with a diameter equal to 100,000 al and a thickness equal to 6000 al. The solar system is about 30,000 ly from the center of the disk. The sun goes around the galaxy in 240 million years, so it has 25 galactic years. . The mass of the Milky Way is 100 billion solar masses. The galaxy is made up of 109 to 1011 stars, interstellar gas and dust.

We also observe extensive light spots called nebulae السديم, A nebula is in astronomy, a celestial object composed of rarefied, ionized gas or interstellar dust. Nebulae play a key role in star formation. Nebulae can form star systems by collapsing under the effect of gravity. Thus, the solar system would have formed from a solar nebula.

Example: the Orion Nebula a which belongs to the Milky Way and the Andromeda Nebula which is located outside our galaxy.

Orion Nebula

Aigle Nebula

The Milkyway Galaxy (Spiral Galaxy)

There are several types of galaxies:

- Spiral galaxies (¼ of all galaxies) have a flattened shape with two spiral arms emerging from the central core. The stars form at these arms.

- Elliptical galaxies (2/3 of all galaxies) have an elliptical or spherical shape with no obvious structure. They are relatively older and emit radio waves (radio galaxies).

- Irregular galaxies (represent less than 1/10 of all galaxies).

The galaxies are ordered in:

Cluster: The galaxy cluster is a group of galaxies. The Milky Way is part of the local cluster along with the Magellanic Cloud and the Andromeda Nebula. The Local Cluster is made up of about twenty galaxies with a radius of about 5000 million light years. The clusters organize themselves to form a higher order structure "the super clusters".

Super clusters: they include several thousand galaxies. The diameter of a supercluster is about ten thousand light years. The local cluster is part of the Virgo Supercluster. The central region of the supercluster is actually a very massive galaxy (several hundred times the size of a normal galaxy) around which other galaxies orbit. This monstrous galaxy is a black hole at the heart of the "Quasar". The Virgo Supercluster has a black hole called Messier 87. There seems to be no larger structure than superclusters.

1-1-2 The expansion of the universe

Stars move at speeds of up to a few hundred km/s. the knowledge of these displacements is highlighted by a property called “Doppler effect” (variation of the frequency according to the displacement of the source).

The Doppler effect makes it possible, from the colors of the stars, to distinguish the stars which are moving away from the earth and those which are approaching it. Those that move away have a color shifted towards red. Those that seem to move towards the earth have a color shifted towards blue. Hubble (1924), stated thatt out of 41 galaxies he studied, 36 were moving away from the earth and only 5 were approaching it.

The speed of receding is proportional to their distance from the earth according to the following formula: $V = H \times d$

d: Distance from the earth in miga parsec (MPC).

H: Hubble constant = 87 ± 7 km/s. MPC

It seems that from a certain distance the galaxies run away from each other as quickly as they are further away. The proportionality between speed and distance of separation has been verified up to 600,000 km/s (20% of the speed of light). We arrive at the vision of an expanding universe from an initial explosion the Big Bang.

1 1 3 Size of the universe

The universe is infinite. It is so because according to Friedman’s model, if the density of the universe is lower than the critical density (1 to 5×10^{-29}) the universe is open and the expansion is eternal. Under these conditions the universe will simply be infinite. The reality is that the density of the universe is 5×10^{-32}, less than the critical density and therefore the universe is infinite.

1 1 4 Age of the universe

The age of the universe is estimated by 03 methods:

1- **Movement of galaxies**: Hubble's observations (1929) allow him to put forward his law saying that the speed of the galaxies moving away from the observer (on earth) is proportional to their distance from the earth:

$V = H xd$

V = distance velocity, H = Hubble constant (87 + 7 km/s mpc), (mpc= mega parsec)

It is therefore possible to calculate the moment when the galaxies were gathered by:

1/H = d/V

The galaxy recession time is an approximation of the age of the universe. This method gives an age of 15 to 20 billion years.

2- **Stellar functioning (star functioning)**: the age of stars can be estimated from the analysis of the chemical elements they consume to ensure their brilliance. The age of the largest star in our galaxy (born at the same time as the galaxy) is 14 to 16 billion years. Research on neighboring galaxies resulted in the same age.

3- **Radioisotopes**: the techniques of radio-chronologies have resulted in an age of 17+ 4 billion years.

In conclusion, the different dating methods give an average age of the universe of 13.8 billion years.

1-2 THE NUCLEOSYNTHESIS

1 2 1: Abundance of chemical elements in the universe:

One of the strengths of the Big Bang theory is that it fairly accurately explains the relative abundance of the chemical elements in the universe.

Nucleosynthesis is the process that creates new atomic nuclei from pre-existing nucleons (protons and neutrons) and nuclei.

1 2 2 Construction of atomic nuclei

The known chemical elements are built from simple elements like a construction set.

a-Elementary particles: There are five (05) types of elementary particles:

Up Quarks (electric charge + 2/3), Down quarks (electric charge -1/3), electrons, neutrinos and photons. Electrons and neutrinos are grouped under the name of leptons.

All matter in the universe is carried by U quarks, D quarks and electrons while the energy is carried by photons and to a lesser degree by neutrinos.

b- Nucleons: they are the particles that constitute the nuclei. Nucleons are protons and neutrons. They are formed from the association of U and D quarks as fellow:

2 U + 1 D -------→ proton (+1 charge)

1 U + 2 D -------→ neutron (Charge 0)

c- Nuclei and atoms:

Nuclei (plural of nucleus); formed by the grouping of nucleons, capture electrons to form atoms. For a given atom the number of protons equals the number of electrons, it defines the atomic number, 1 for hydrogen, 2 for helium, etc.

If we start from the simplest nucleus, that of hydrogen (1proton) if we add a neutron to it we will have a nucleus of mass +2 and charge +1, it is still hydrogen but heavier, it is called deuterium. The fusion of two deuterium nuclei produces a more stable nucleus (2 protons and 2 neutrons) called Helium. Then, 3 Helium nuclei give a Carbon of charge +6 and mass 12, then ^{12}C + He -----→ ^{16}O etc. Each neutron capture operation is a nuclear reaction.

Nuclear reactions release a considerable amount of energy and at the same time require extreme temperatures to occur. To form hydrogen it takes a temperature of 1 Million degrees, 100 Million degrees to fuse two helium nuclei and 600 Million degrees to unite the nuclei of oxygen and hydrogen. In conclusion, nucleosynthesis requires a medium that is hot enough to occur and also cold enough to save the products.

1 2 3 Nucleosynthesis and the evolution of the universe:

The synthesis of the nuclei could have been achieved during the evolution of the universe from the initial explosion (Big Bang).

This phenomenon took place in 04 stages in different environments, the cosmos, the stars, the interstellar medium and the planets.

1-Phase 1: Big Bang Nucleosynthesis (primordial nucleosynthesis)

The first nuclei were formed a few minutes after the Big Bang, through nuclear reactions in a process called Big Bang nucleosynthesis.[1] After about 20 minutes, the universe had expanded and cooled to a point at which these high-energy collisions among nucleons ended, so only the fastest and simplest reactions occurred, leaving our universe containing hydrogen and helium. The rest is traces of other elements such as lithium and the hydrogen isotope deuterium.

In physical cosmology, **Big Bang nucleosynthesis** (also known as **primordial nucleosynthesis**, and abbreviated as **BBN**)[1] is the production of nuclei other than those of the lightest isotope of hydrogen (hydrogen-1, ^{1}H, having a single proton as a nucleus) during the early phases of the universe. This type of nucleosynthesis is thought by most cosmologists to have occurred from 10 seconds to 20 minutes after the Big Bang.[2] It is thought to be responsible for the formation of most of the universe's helium (as isotope helium-4 (^{4}He)), along with small amounts of the hydrogen isotope deuterium (^{2}H or D), the helium isotope helium-3 (^{3}He), and a very small amount of the lithium isotope lithium-7 (^{7}Li). In addition to these stable nuclei, two unstable or radioactive isotopes were produced: the heavy hydrogen isotope tritium (^{3}H or T) and the beryllium isotope beryllium-7 (^{7}Be). These unstable isotopes later decayed into ^{3}He and ^{7}Li, respectively, as above.

With the drop in temperature necessary for nuclear fusion, the universe experiences its first growing crisis which lasts a million years. The temperature has dropped and this has allowed the transition from the nuclear field to the field of electromagnetism.

The protons are then able to capture an electron to form hydrogen atoms. With the decrease in temperature, the population of atoms increases and around T= 3000°k the universe is formed by hydrogen and helium atoms. At the moment the universe is entering a second time in crisis because the hydrogen molecule is a closed structure which is difficult to combine. The energy of the universe, at the moment, contained in matter is preponderant compared to that of radiation.

b- The stellar phase (stellar nucleosynthesis) مرحلة النجوم:

In this phase, under the effect of the expansion and the decrease in temperature, the probabilities of association become increasingly weak. Gravity condenses the aggregations of matter to give rise to galaxies. Within them, the condensation of gaseous matter gives rise to stars. Gravitational phenomena within stars cause a rise in temperature allowing the triggering of nuclear reactions, to produce the energy necessary for the luminosity of the star. At first it is hydrogen which is the nuclear fuel (case of the sun for 4.5 billion years and for the next 5 billion years). Once the hydrogen is exhausted, the star contracts again, the temperature increases and it is helium which will this time be the nuclear fuel. When the helium is finished in the core of the star, the contraction resumes and the temperature increases (1Billion degrees) and it is the carbon which will be the nuclear fuel and gives birth to Ne, Na, Al, Si, P, S. After the exhaustion of Carbon, the star contracts again the temperature increases to 2 at 5 billion degrees, the nuclear fuel will be Neon then oxygen and finally Silicon producing Fe, Ni, Cr and Zn. At 5 billion degrees the thermal energy risks exceeding the binding energy of the nucleons. There then occurs a gigantic explosion known by SUPERNOVA which evacuates the heavy elements synthesized into space. The remaining stellar residue gives rise to the PULSAR (neutron star).

c- The interstellar phase: (in the **interstellar medium)**

In astronomy, the **interstellar medium (ISM)** is the matter and radiation that exist in the space between the star systems in a galaxy. This matter includes gas in ionic, atomic, and molecular form, as well as dust and cosmic rays. It fills interstellar space and blends smoothly into the surrounding intergalactic space. The energy that occupies the same volume, in the form of electromagnetic radiation, is the **interstellar radiation field**

In this phase the dust resulting from the explosion of supernova and planetary nebulae at a temperature of a few tens of absolute degrees hydrogen combines with heavy atoms to give water, ammonia, methane and hydrocarbon. In this phase the atoms of Li, Be and B are synthesized following the bombardment by the cosmic rays of oxygen, nitrogen and carbon.

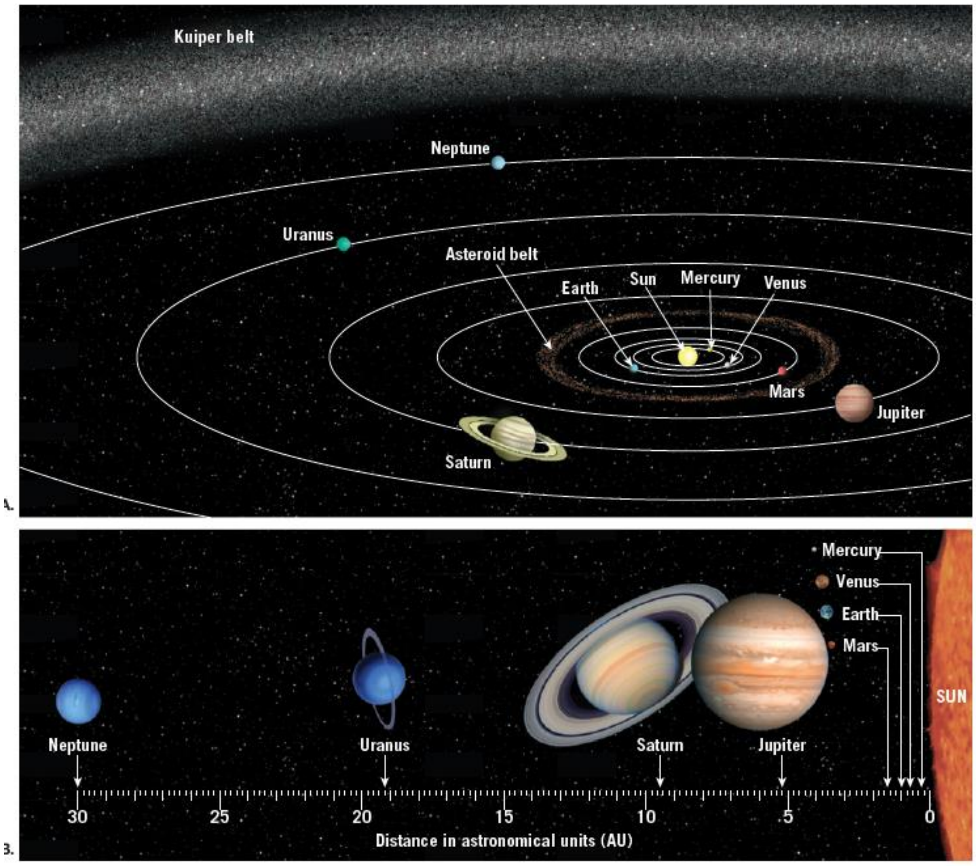
d- The planetary phase: (the planetary medium)

The medium of the planets helps molecular evolution by its density which promotes contact between elements, and by its temperature which accelerates reactions without destroying fragile molecules.

THE SOLAR SYSTEM:
An Overview

The Sun is at the center of a revolving system, trillions of miles wide, consisting of eight planets, their satellites, and numerous smaller asteroids, comets, and meteoroids. An estimated 99.85 percent of the mass of our solar system is contained within the Sun. Collectively, the planets account for most of the remaining 0.15 percent. Starting from the Sun, the planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune (**Figure 1**). Pluto was recently reclassified as a member of a new class of solar system bodies called *dwarf planets.*

The solar system was born 4.55 billion years ago from a solar nebula.



SMARTFIGURE 24.1
Orbits of the planets
A. Artistic view of the solar system, in which planets are not drawn to scale.
B. Positions of the planets shown to scale using astronomical units (AU), where 1 AU is equal to the distance from Earth to the Sun—150 million kilometers (93 million miles).

All the particles of this solar nebula, remnant of a supernova, began to turn quietly and to attract each other. Upon revolving, this cloud has warmed up and in the center; the material has contracted on itself, which has given birth to a hot proto-sun, our sun. The remaining materials formed a thick, flattened, rotating disk, within which matter gradually cooled and condensed into grains and then bodies of asteroid size called **planetesimals**.

Planets are non-luminous bodies that revolve around the Sun (fig.1). These planets are divided into two families:

- **Terrestrial planets**, **telluric planets**, or **rocky planets** (Mercury, Venus, Earth and Mars) are of modest size but have a high density and a thin layer of atmosphere because their gravity is high.

TABLE 24.1 Planetary Data

Planet	Symbol	AU*	Mean Distance from Sun: Millions of Miles	Mean Distance from Sun: Millions of Kilometers	Period of Revolution	Inclination of Orbit	Orbital Velocity: mi/s	Orbital Velocity: km/s
Mercury	☿	0.39	36	58	88^d	7°00'	29.5	47.5
Venus	♀	0.72	67	108	225^d	3°24'	21.8	35.0
Earth	⊕	1.00	93	150	365.25^d	0°00'	18.5	29.8
Mars	♂	1.52	142	228	687^d	1°51'	14.9	24.1
Jupiter	♃	5.20	483	778	12^{yr}	1°18'	8.1	13.1
Saturn	♄	9.54	886	1427	30^{yr}	2°29'	6.0	9.6
Uranus	♅	19.18	1783	2870	84^{yr}	0°46'	4.2	6.8
Neptune	♆	30.06	2794	4497	165^{yr}	1°46'	3.3	5.3

Planet	Period of Rotation	Diameter: Miles	Diameter: Kilometers	Relative Mass (Earth = 1)	Average Density (g/cm^3)	Polar Flattening (%)	Eccentricity†	Number of Known Satellites‡
Mercury	59^d	3015	4878	0.06	5.4	0.0	0.206	0
Venus	243^d	7526	12,104	0.82	5.2	0.0	0.007	0
Earth	$23^h56^m04^s$	7920	12,756	1.00	5.5	0.3	0.017	1
Mars	$24^h37^m23^s$	4216	6794	0.11	3.9	0.5	0.093	2
Jupiter	9^h56^m	88,700	143,884	317.87	1.3	6.7	0.048	67
Saturn	10^h30^m	75,000	120,536	95.14	0.7	10.4	0.056	62
Uranus	17^h14^m	29,000	51,118	14.56	1.2	2.3	0.047	27
Neptune	16^h07^m	28,900	50,530	17.21	1.7	1.8	0.009	13

*AU = astronomical unit, Earth's mean distance from the Sun.

†Eccentricity is a measure of the amount an orbit deviates from a circular shape. The larger the number, the less circular the orbit.

‡Includes all satellites discovered as of December 2012

- **The Jovian planets (giant planets)** (Jupiter, Saturn, Uranus and Neptune), are the most distant and the largest. They have a much lower density. They are composed of a thick layer of hydrogen and helium surrounding a massive ice core. These planets have many satellites and more or less well developed rings.

2- Planets internal structures and atmospheres

All the planets fall into two groups based on location, size, and density: the **terrestrial (Earth like planets** (Mercury, Venus, Earth, and Mars), and the **Jovian) planets (Jupiter-like)** (Jupiter, Saturn, Uranus, and Neptune). Because of their relative locations, the four terrestrial planets are also known as *inner planets*, and the four Jovian planets are known as *outer planets*.

A correlation exists between planetary locations and sizes:

The inner planets are substantially smaller than the outer planets, also known as *gas giants*. For example, Neptune's diameter four times the diameter of Earth.

Furthermore, Neptune's mass is 17 times greater than that of Earth or Venus.

Other properties that differ among the planets include densities, chemical compositions, orbital periods, and numbers of satellites.

The average density of the terrestrial planets is about five times the density of water, whereas the average density of the Jovian planets is only 1.5 times that of water. Saturn has a density only 0.7 times that of water, which means that it would float in a sufficiently large tank of water. The outer planets are also characterized by long orbital periods and numerous satellites.

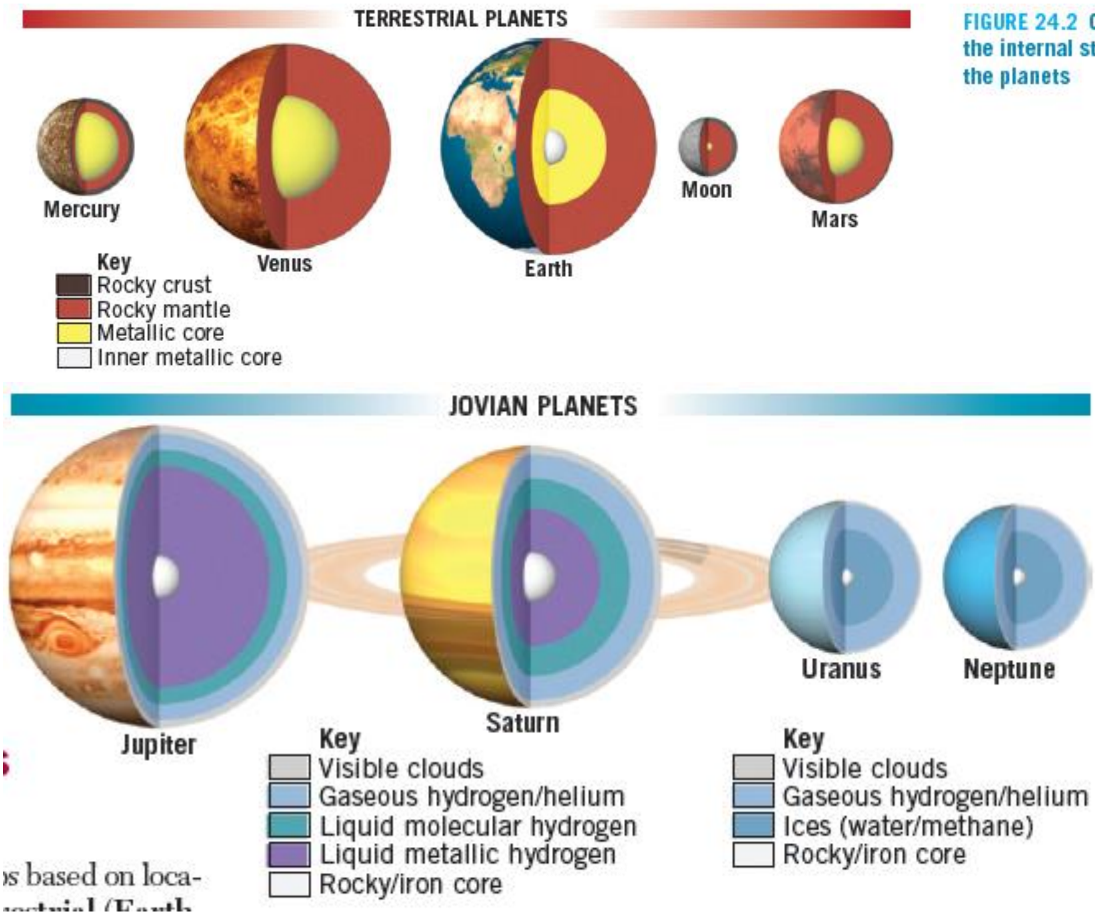


FIGURE 24.2 Comparing the internal structures of the planets

2.1 Planets internal structures:

Shortly after Earth formed, segregation of material resulted in the formation of three major layers, defined by their chemical composition—the **crust, mantle, and core**. This type of chemical separation occurred in the other planets as well.

The **terrestrial planets** are compositionally different from the **Jovian planets**, the nature of these layers is different as well (**Figure 24.2**).

The terrestrial planets are **dense**, having relatively **large cores of iron and nickel**.

The outer cores of **Earth and Mercury are liquid**, whereas the cores of **Venus and Mars** are thought to be only **partially molten**.

This difference is attributable to **Venus and Mars having lower internal temperatures** than those of **Earth and Mercury**. Silicate minerals and other lighter compounds make up the mantles of the terrestrial planets. Finally, the silicate crusts of terrestrial planets are relatively thin compared to their mantles.

The two largest Jovian planets, **Jupiter and Saturn**, likely have small, solid cores consisting of iron compounds, like the cores of the terrestrial planets, and rocky material similar to Earth's mantle.

Progressing outward, the layer above the core consists of liquid hydrogen that is under extremely high temperatures and pressures.

Saturn's magnetic field is much weaker than Jupiter's, due to its smaller shell of liquid metallic hydrogen. The outermost layers are gases of hydrogen and helium, as well as ices of water, ammonia, and methane—which mainly account for the low densities of these giants.

Uranus and Neptune also have small iron-rich, rocky cores, but their mantles are likely hot, dense water and ammonia. Above their mantles, the amount of hydrogen and helium increases.

All planets, except Venus and Mars, have significant magnetic fields.

2.2 The Atmospheres of the Planets:

The Jovian planets have very thick atmospheres composed mainly of hydrogen and helium, with lesser amounts of water, methane, ammonia, and other hydrocarbons.

By contrast, the terrestrial planets, including Earth, have relatively meager atmospheres

During planetary formation, the inner regions of the developing solar system were too hot for ices and gases to condense. By contrast, the Jovian planets formed where temperatures were low and solar heating of planetesimals was minimal. This allowed water vapor, ammonia, and methane to condense into ices. Hence, the gas giants contain large amounts of these volatiles. As the planets grew, the largest Jovian planets, Jupiter and Saturn, also attracted large quantities of the lightest gases, hydrogen and helium.

How did Earth acquire water and other volatile gases? It seems that early in the history of the solar system, gravitational tugs by the developing protoplanets sent planetesimals into very eccentric orbits. As a result, Earth was bombarded with icy objects that originated beyond the orbit of Mars. This was a fortuitous event for organisms that currently inhabit our planet. Mercury, our Moon, and numerous other small bodies lack significant atmospheres even though they certainly would have been bombarded by icy bodies early in their development. Airless bodies develop where solar heating is strong and/or gravities are weak. Simply stated, *small warm bodies* have a better chance of losing their atmospheres because gas molecules are more energetic and need less speed to escape their weak gravities. For example, warm bodies with small surface gravity, such as our Moon, are unable to hold even heavy gases such as carbon dioxide and nitrogen. Mercury is massive enough to hold trace amounts of hydrogen, helium, and oxygen gas.

The slightly larger terrestrial planets, Earth, Venus, and Mars, retain some heavy gases, including water vapor, nitrogen, and carbon dioxide. However, their atmospheres are miniscule compared to their total mass. Early in their development, the terrestrial planets probably had much thicker atmospheres. Over time, however, these primitive atmospheres gradually changed as light gases trickled away into space.

For example, Earth's atmosphere continues to leak hydrogen and helium (the two lightest gases) into space. This phenomenon occurs near the top of Earth's atmosphere, where air is so tenuous that nothing stops the fastest-moving particles from flying off into space.

The speed required to escape a planet's gravity is called **escape velocity**. Because hydrogen is the lightest gas, it most easily reaches the speed needed to overcome Earth's gravity. Billions of years in the future, the loss of hydrogen (one of the components of water) will eventually "dry out" Earth's oceans, ending its hydrologic cycle.

Life, however, may remain sustainable in Earth's polar regions.

The massive Jovian planets have strong gravitational fields and thick atmospheres. Furthermore, because of their great distance from the Sun, solar heating is minimal. This explains why Saturn's moon Titan, which is small compared to Earth but much further from the Sun, retains an atmosphere. Because the molecular motion of a gas is temperature dependent, even hydrogen and helium move too slowly to escape the gravitational pull of the Jovian planets.