CHAPTER 3: MATTER, ENERGY, AND THE UNIVERSE

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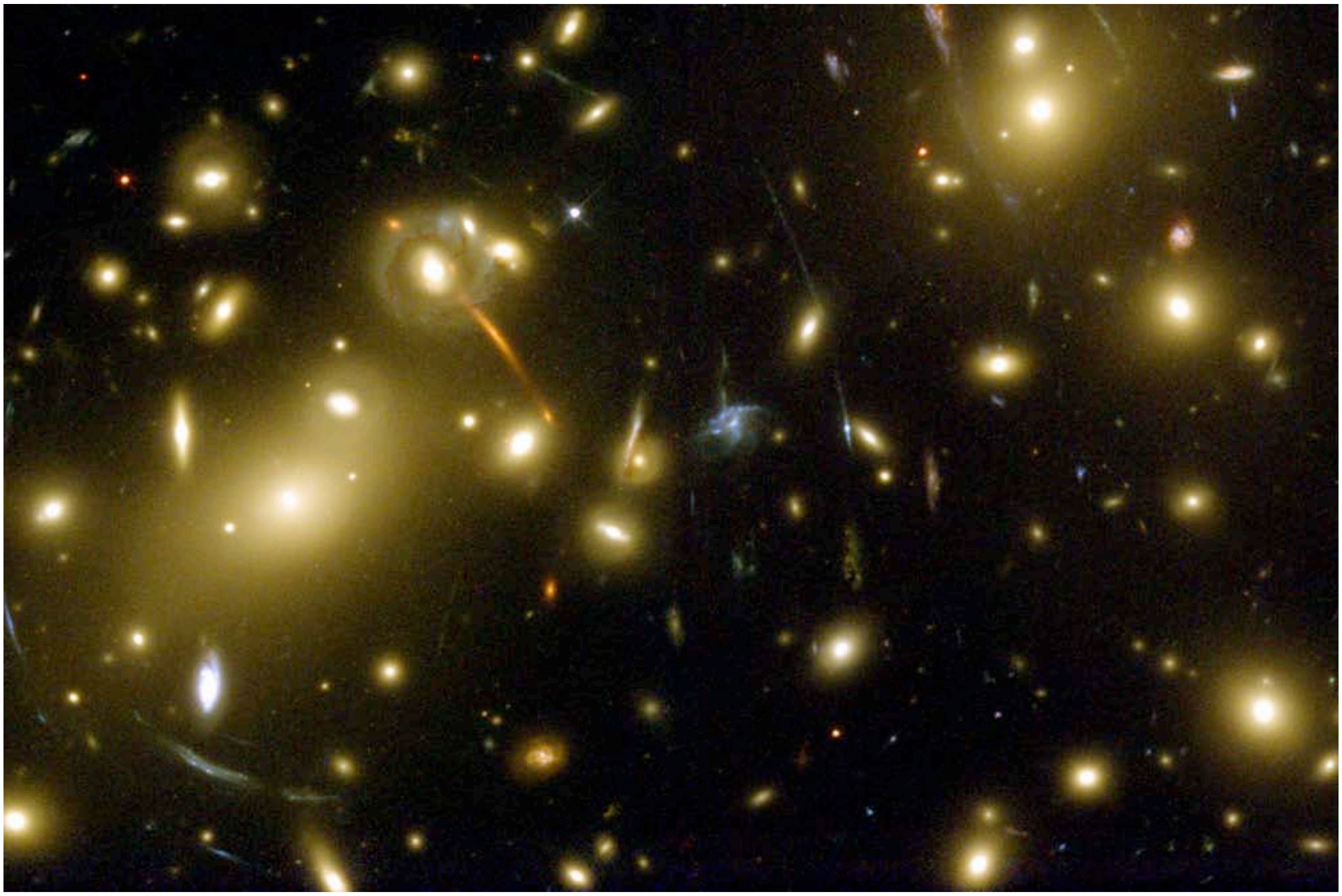


Hubble Space Telescope view of a distant cluster of galaxies near the beginning of time. The distance of these cosmic features was estimated to be about 13.4 billion light-years from Earth. [*Credit: NASA, ESA, Richard Ellis (Caltech) and Jean-Paul Kneib (Observatoire Midi-Pyrenees, France) Acknowledgment: NASA, A. Fruchter and the ERO Team (STScI and ST-ECF)*]

STUDENT LEARNING OUTCOMES

After reading this chapter you should be able to:

- Describe the creation and structure of the Universe.
- Outline the characteristics of the various planets and dwarf planets found in our solar system.
- Explain the structure of matter at the atomic and molecular level.
- Describe the forms and structure of inorganic and organic matter.
- Define the various forms of energy.
- Outline the laws of thermodynamics.
- Identify the role of conduction, convection, and radiation in transporting heat energy.
- Discuss how life uses photosynthesis and cellular respiration to capture and use energy.

THE UNIVERSE AND OUR SOLAR SYSTEM

The primary goal of this textbook is to describe the physical geography of our planet. To accomplish this goal we must gain some basic understanding of the phenomena that exist outside of the Earth's atmosphere in the void of space. This exploration will explain how the Earth came about and allow us to compare the characteristics of the planets found in our solar system. We will also learn that our planet and solar system is a very insignificant part of the Universe in terms of spatial scale. Yet, as far as we know the Earth is the only place in the Universe that is home to life. So how did the Universe begin and what are some of the major structures found within its boundaries? A theory is presented next to describe the origin of the Universe.

THE BIG BANG THEORY

About 13.7 billion years ago all of the matter and energy in the Universe was concentrated into an area the size of an atom. At this instant, matter, energy, space, and time did not exist. Then suddenly, the Universe began to expand at an incredible rate and matter, energy, space, and time came into being. This event has been called the **Big Bang**. As the Universe grew rapidly in size, matter began to coalesce into gas clouds, and then stars and planets. Our solar system formed about 5 billion years ago when the Universe was about 65% of its present size. Today, the Universe continues to expand outward.

The acceptance of this theory by the scientific community is based on a number of observations. These observations confirm specific predictions of the Big Bang theory. In a previous chapter, we learned that scientists test their theories through deduction, falsification, and predictions. Predictions associated with the Big Bang theory that have been tested scientifically are:

- If the Big Bang did occur, all of the objects within the Universe should be moving away from each other. In 1929, Edwin Hubble documented that the galaxies in our Universe are indeed moving away from each other (Hubble, 1929).

- The Big Bang should have left an afterglow from the explosion. In the 1960s, scientists discovered the existence of **cosmic radiation**, the background afterglow created by the Big Bang explosion (Penzias and Wilson, 1965). Our most accurate measurements of this cosmic radiation came in November 1989, from the *Cosmic Background Explorer (COBE) satellite*. Measurements from this satellite tested an important prediction of the Big Bang theory: that the initial explosion that gave birth to the Universe should have created radiation with a spectrum that follows a blackbody curve. The COBE measurements indicated that the spectrum of the cosmic radiation did indeed follow a blackbody curve (Smoot et al., 1992).

- If the Universe began with a Big Bang, extreme temperatures should have caused 25% of the mass of the Universe to become helium (Harrison, 2000). This is exactly what is observed.

- Matter in the Universe should be distributed homogeneously. Astronomical observations from the Hubble Space Telescope do indicate that matter in the Universe generally has a homogeneous distribution.

Modern cosmologists have postulated three possible endings to the Universe (Harrison, 2000). If the Universe is infinite or has no edge, it could continue to expand forever. The Universe could be expanding at a rate that becomes gradually slower with elapsed time. When the expansion rate becomes zero, the Universe will stop growing and it will reach its equilibrium size. The final scenario suggests that if the Universe is finite or closed, gravity will cause the Universe to collapse when the expansion stops. This collapse would end when all matter and energy is compressed into the high energy, high-density state from which the Universe began. This end event is suitably called the **Big Crunch**. Some theorists have suggested that the Big Crunch will produce a new Big Bang and the process of an expanding Universe will begin again. This idea is called the **Oscillating Universe Theory** (Tolman, 1934).

STRUCTURE OF THE UNIVERSE

Our knowledge of the structure of the **Universe** is based on data from various instruments aboard satellites (**Figure 3.1**) and observations from optical and radio telescopes located on the Earth's surface (**Figure 3.2**). Through these devices we have discovered a number of unique celestial objects. The existence of some of these things ended a very long time ago. We still see them today because they are incredible distances away from our planet. It is very hard to imagine how far some of these

FIGURE 3.1 Since its launch in 1990, the orbiting Hubble Space Telescope has provided scientists with exceptional views of objects found in the Universe. *(Source: NASA)*

distances are. But consider the fact the **speed of light** is 9.46 trillion km per year (one **light-year**) and the fact that it took light from these objects billions of years to reach us! In comparison, light from the Sun takes about 8 minutes to reach the Earth over a distance of about 149.5 million km (92.9 million mi).

Astronomers estimate that the diameter of the Universe is between 30 to 40 billion light-years. Within this large area, gravity has caused matter to randomly concentrate to create a variety of celestial bodies. The most obvious of these are the luminous stars that we see in our sky at night. **Stars** are formed when massive concentrations of interstellar hydrogen gas collapse inward because of gravity. Stars generate their light energy through nuclear reactions that cause hydrogen nuclei to fuse into helium nuclei at their core. These nuclear fusion reactions occur because the enormous mass of the star creates a gravitational force strong enough to bind atoms together. A star's **nuclear fusion** reactions also produce an interior temperature that is greater than 15 million °C (27 million °F). The migration of this heat energy to the star's surface then produces an emission of electromagnetic radiation (star light) that radiates outwards to space.

FIGURE 3.2 The Parkes Radio Telescope is located about 400 kilometers west of Sydney, Australia. Radio telescopes are quite different from optical telescopes. Instead of lenses and mirrors to capture visible light, they use a large curved dish and an antenna to view the Universe by receiving radio waves. Viewing the Universe with the radio band of radiation allows us to see phenomena that are invisible to optical telescopes.

(Source: http://www.cmis.csiro.au/)

FIGURE 3.3 Hubble Space Telescope image of the dusty spiral galaxy NGC 4414. (*Credit: Hubble Heritage Team (AURA/STScI/ NASA)*

Stars tend to be organized in much larger bodies known as a **galaxy** (**Figure 3.3**). Within a galaxy we can find billions of stars and large concentrations of gas and dust. The **Milky Way Galaxy**, which is home to our Sun, is believed to contain over 200 billion stars and has a diameter of about 100,000 light-years. The Milky Way is also a member of a cluster of three large and over 30 smaller galaxies. This cluster measures about three million light-years in diameter. Astronomers call such clusters of galaxies a local group. Most local groups belong to yet bigger structures in the Universe. These structures consist of a collection of many local groups to form a local supercluster. These celestial objects are the largest features in our Universe measuring about 100 million light-years across.

A typical galaxy consists of three parts: the disk, the nuclear bulge, and the halo (**Figure 3.4**). The disk consists of all the matter distributed along a plane of rotation. This

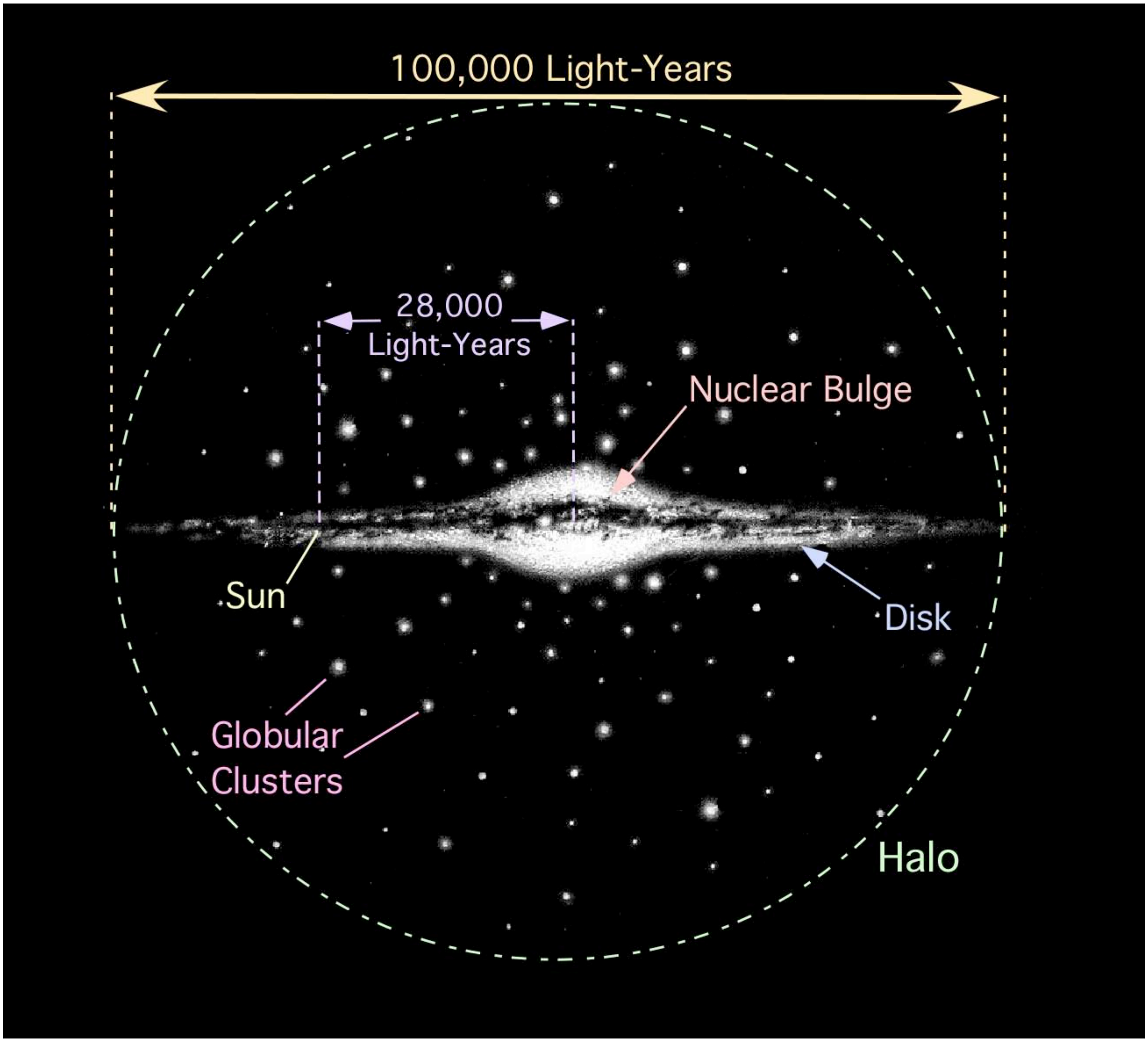


FIGURE 3.4 Typical features of a galaxy. The following image is a representation of the Milky Way Galaxy (edge-on view). There are three main components to a typical galaxy: the disk, the nuclear bulge, and the halo. The disk is a mass of rotating young stars, gas, and dust that is oriented along a flat plane. The nuclear bulge is found at the center of the galaxy and contains a dense mixture of young and old stars. The halo is a large somewhat spherical void that contains only a few scattered old stars and large spherical clusters of stars known as globular clusters. The relative position of the Sun is also shown. *(Image Copyright: Michael Pidwirny)*

includes young stars, clusters of stars, and most of the galaxy's gas and dust. The matter found in the disk is often organized into several spiral arms. The presence of these spiral arms indicates that the disk is moving. The nuclear bulge is located at the heart of the galaxy. This almost spherical feature is made up of a dense concentration of young and old stars. Observations of the nuclear bulge suggest that it lacks gas and dust. The halo is a thin cloud of stars and star clusters (called globular clusters) that surrounds the disk and nuclear bulge. It also contains very little gas, and as a result, relatively few stars exist here.

The Solar System

Stars often have a number of objects orbiting around them in an adjacent region of space known as a **solar system**. Our solar system formed about five billion years ago and consists of the **Sun**, eight planets, at least thee dwarf planets, about 130 satellites, and a large number of comets and asteroids. A **planet** can be defined according to the following criteria: 1) It is a celestial body that orbits a star, 2) it has cleared the space along its orbital path of objects, 3) self-gravitational force has shaped its surface to be nearly spherical, and 4) it does not have the ability to generate its own light. The definition of a **dwarf planet** meets all the criteria of a planet, except that it has not cleared the space along its orbital path of objects. **Satellites** are bodies that orbit around planets and dwarf planets. The Earth's moon is considered to be a satellite. An **asteroid** is a small, rocky, planet-like object that orbits the Sun. Several tens of thousands of these objects are found in a dense band between Mars and Jupiter. A **comet** is a small body of ice and dust that orbits the Sun. The orbit of comets tends to be very elongated and elliptical. When these objects get close to the Sun, the ice vaporizes producing a breathtaking glowing tail.

The orbits of most of our solar system's planets are almost circular ellipses. Mercury and Pluto are the exceptions and their orbits tend to be more oval shaped. The orbits of the planets are also more or less at the same ecliptic plane. This ecliptic plane is tilted an average of about 7° from the plane of the Sun's equator. Pluto's orbit tilts with an inclination of 17°. Some other characteristics of our solar system's planets are described in **Table 3.1**.

The Inner Solar System

Astronomers usually divide our solar system into two parts: the inner and outer solar system. The inner solar system contains the planets Mercury, Venus, Earth, and Mars (**Figure 3.5**). Of this group of planets, **Mercury** is the closest to the Sun (**Figure 3.6**). The distance of Mercury from the Sun varies between 46 and 70 million

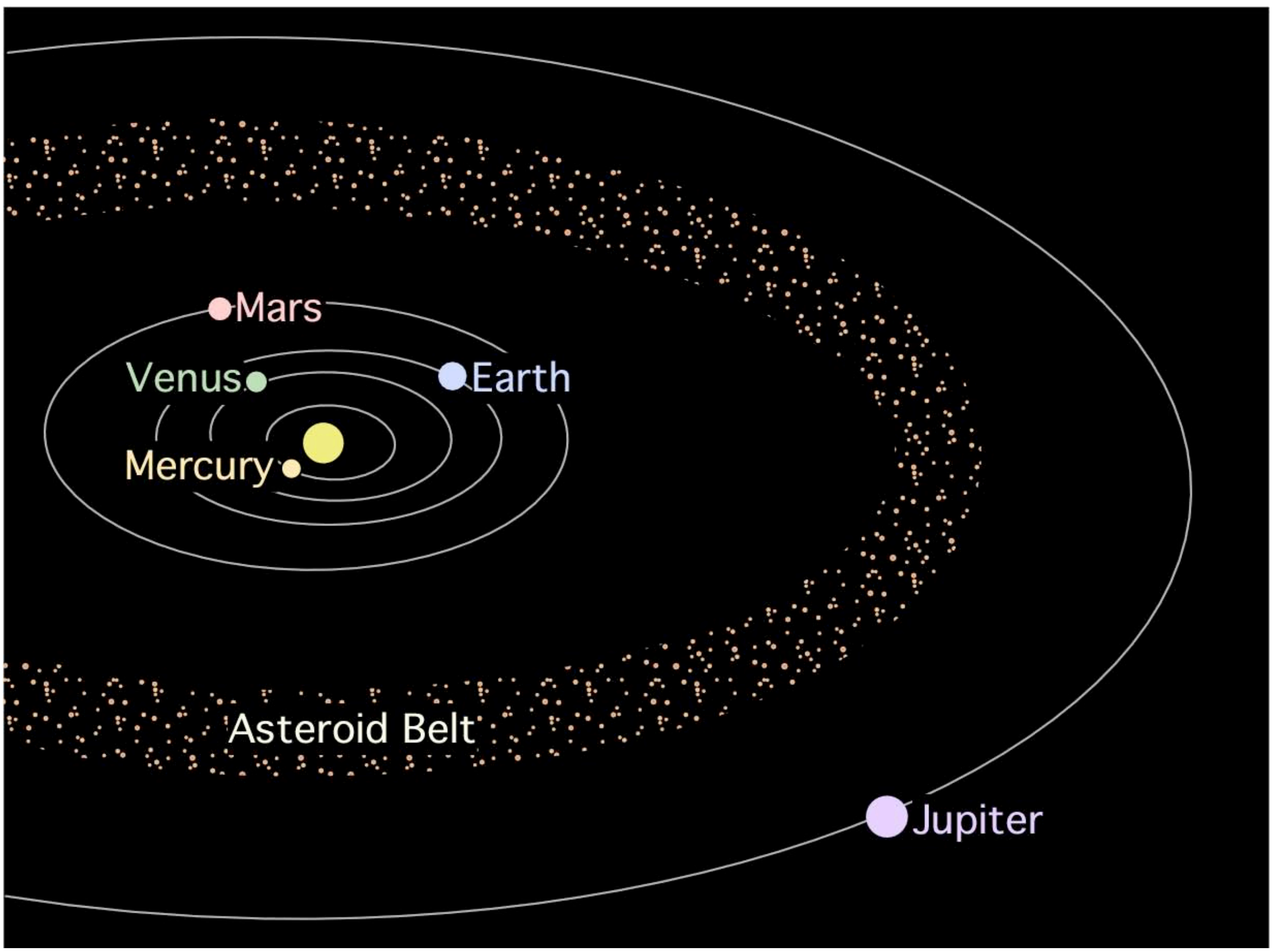


FIGURE 3.5 The inner solar system consists of the Sun, Mercury, Venus, Earth, and Mars. It is separated from the outer solar system (Jupiter, Saturn, Uranus, Neptune, and Pluto) by a dense zone of asteroids found between the orbits of Mars and Jupiter. *(Image Copyright: Michael Pidwirny)*

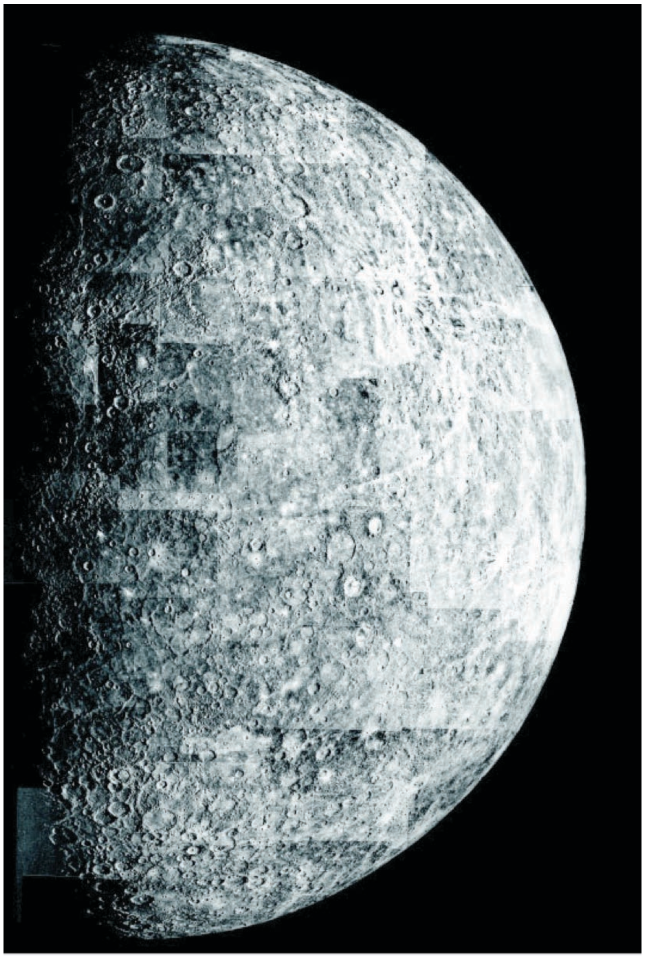


FIGURE 3.6 Mariner 10 image of Mercury from 1974. Note how the surface of Mercury shows numerous crators and resembles Earth's moon. *(Source: NASA)*

km or between 28.6 and 43.5 million mi (average about 57.9 million km or 36.0 million mi). Surface temperatures on Mercury vary from -200°C (-328°F) to 430°C (806°F). This is in part due to its closeness to the Sun and the fact that its rotation is relatively slow (about 59 days to complete one cycle). When turned away from the Sun, Mercury's surface experiences a big drop in temperature because it does not receive sunlight for an extended period of time. No other planet in our solar system has as great a diurnal temperature variation and only Venus is hotter. Mercury has a very thin atmosphere composed mainly of sodium, potassium, and helium. Mercury's surface is heavily cratered from meteorites. It is also very old and has no tectonic system to renew the surface crust.

Venus is the second planet from the Sun with an average orbital distance of 108.2 million km or 67.2 million mi (**Figure 3.7**). The size and mass of this planet are very similar to those of Earth. However, the other characteristics of Venus are quite different from our planet. For example, Venus' rotation is very slow (243 Earth days) and the direction of movement when viewed from the North Pole is in a clockwise direction (Earth's rotation is counter-clockwise when viewed from the North Pole). The atmosphere of Venus is composed of mainly carbon dioxide and is about 90 times more dense then Earth's air. The carbon dioxide rich atmosphere creates an extreme greenhouse effect that results in surface temperatures of around 467°C (873°F), which is hot enough to melt lead. Venus' atmosphere also contains a number of cloud layers that are several kilometers thick and composed of sulfuric acid. Radar images from the Magellan satellite indicate that a wide variety of interesting and unique landform features exist on the surface of Venus. One mountain called Maxwell Montes reaches an altitude of 12 km or 7.5 mi (Mt. Everest is 8.8 km or 5.5 mi in elevation). Planetary geologists speculate that the oldest terrains on Venus are only about 800 million years old. Extensive volcanism at that time is believed to have destroyed the earlier surface and left a number of relatively young volcanic landforms.

Our home, **Earth**, is the third planet from the Sun. What makes Earth so interesting as a planet is that it supports life. As far as we know, no other planet in our solar system has a biosphere. The development of a

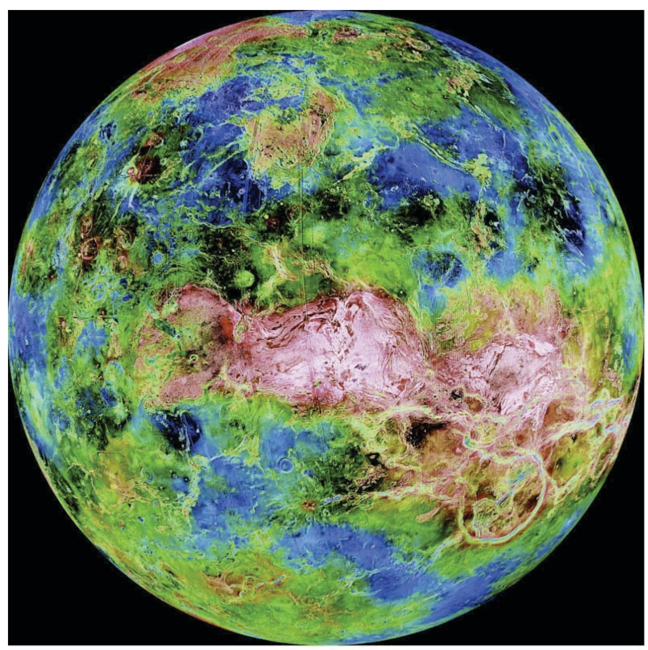


FIGURE 3.7 Radar image of the surface Venus from the 1990-1994 Magellan mission. Radar was able to penetrate the thick clouds that normally obscure the ground surface of this planet. The Magellan spacecraft imaged more than 98% of Venus at a resolution of about 100 meters. *(Source: NASA)*

biosphere can only occur with the right mixture of planetary characteristics. For example, Earth's atmosphere contains enough oxygen and carbon dioxide to allow for plant photosynthesis, and plant and animal cellular respiration. The particular orbital and rotational characteristics of the Earth help to maintain a range of surface temperatures that encourages the existence of organisms. Lastly, Earth's unique size and mass cause a gravitation force that is not too strong or too weak for life. A higher gravitational force would crush living cells and would not allow organisms to develop vertical body shapes. A weaker gravitational force would have never caused important gases needed by life to accumulate in the atmosphere.

The last planet in the inner solar system is **Mars** (**Figure 3.8**) with an average distance from Sun of 227.9 million km (141.6 million mi). Mars has especially fascinated scientists because observing it with Earth-based telescope revealed recognizable surface details. For many years, astronomers were convinced that these features could have only been produced by intelligent life. Better observing technologies in the second half of the 20th century suggested that these features were misidentified. Further, several space missions that landed scientific instruments on the surface of Mars in 1976 and in 1997 failed to find conclusive evidence for even microscopic life. However, in 1996, David McKay and his research colleagues announced in the prestigious journal Science the discovery of organic compounds in a meteorite of Martian origin (McKay et al., 1996). These scientists further theorized that these compounds, in combination with a number of other mineralogical features observed in the meteorite, maybe evidence of ancient Martian microorganisms!

During its orbit, Mars' distance from the Sun varies by about 42.6 million km (26.5 million mi). This significant change in solar distance causes the Martian average surface temperature to vary by about 30°C (54°F) near the equator annually. In comparison, annual average surface temperatures along Earth's equator vary at most by 5°C

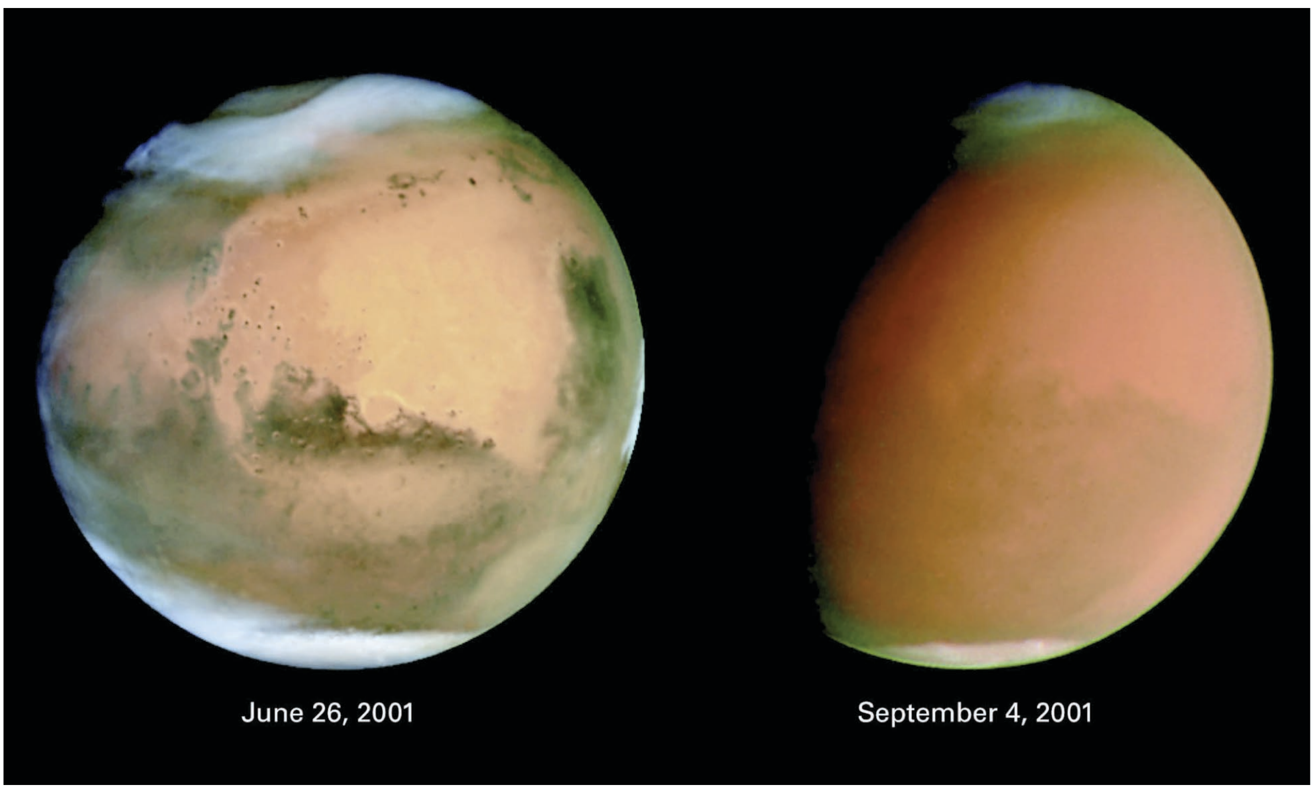


FIGURE 3.8 Mars the fourth planet from the Sun. The Hubble Space Telescope captured these two dramatically different images of our planetary neighbor Mars. These images show how a global dust storm engulfed Mars with the onset of Martian spring in the Southern Hemisphere. When NASA's Hubble Space Telescope imaged Mars in June, two small storms were seen in the giant Hellas Basin and at the northern polar cap. When Hubble photographed the planet again in early September, the storms had already been raging across the planet for nearly two months obscuring all surface features with a thick layer of dust. This is the largest dust storm seen in several decades of observing Mars. *(Source: Hubble Space Telescope)*

(9°F). Across the Martian globe surface temperatures range from a chilling -133°C (-207°F) at the winter pole under conditions of complete darkness to almost 27°C (81°F) near the equator during summer. Mars has a very thin atmosphere composed primarily of carbon dioxide (95.3%), nitrogen (2.7%), argon (1.6%), oxygen (0.15%), and traces of water (0.03%). The average atmospheric pressure on the surface of Mars is 0.7% of Earth's. Mars has a very interesting landscape. Satellite images have found evidence of water erosion in many places on Mars. Such surface features suggest that flowing water has occurred in the past. Mars is also home to the solar system's tallest mountain. Volcanic Olympus Mons extends 27 km (16.8 mi) in elevation from its surrounding plain. Mars has two tiny moons that orbit very close to its surface.

The Outer Solar System

The outer solar system contains the dwarf planet Pluto and planets Jupiter, Saturn, Uranus, and Neptune (**Figure 3.9**). Jupiter, Saturn, Uranus, and Neptune are quite different from the planets that we have already discussed. All of these planets are quite large in size and their total mass accounts for more than 99% of the matter found in our solar system (excluding the Sun). Also, these four planets do not have solid surfaces. Instead, their masses are mainly composed of hydrogen and helium gas that becomes increasing dense as you travel from the edge of their atmosphere towards the planet's interior.

Jupiter is the largest planet in our solar system (**Figure 3.10**). This gas giant has a volume that is approximately 1000 times greater than the Earth (one-tenth the size of the Sun). Temperatures on the planet's cloud surface are about -121°C (-186°F). Jupiter radiates more energy into space than it receives from the Sun because the interior of the planet is quite hot. Scientists estimate that the core has a temperature of about 20,000°C (36,000°F). This heat is generated by the slow gravitational compression of the planet. Most researchers believe that Jupiter may have a relatively small solid rocky core that has a mass of 10 to 15 Earths. Above this solid core is a layer of liquid metallic hydrogen (hydrogen with ionized protons and electrons). This unique form of hydrogen can only exist under conditions of extreme pressure and temperature. Such conditions occur only in the deep interiors of Jupiter and Saturn. On top of the liquid metal

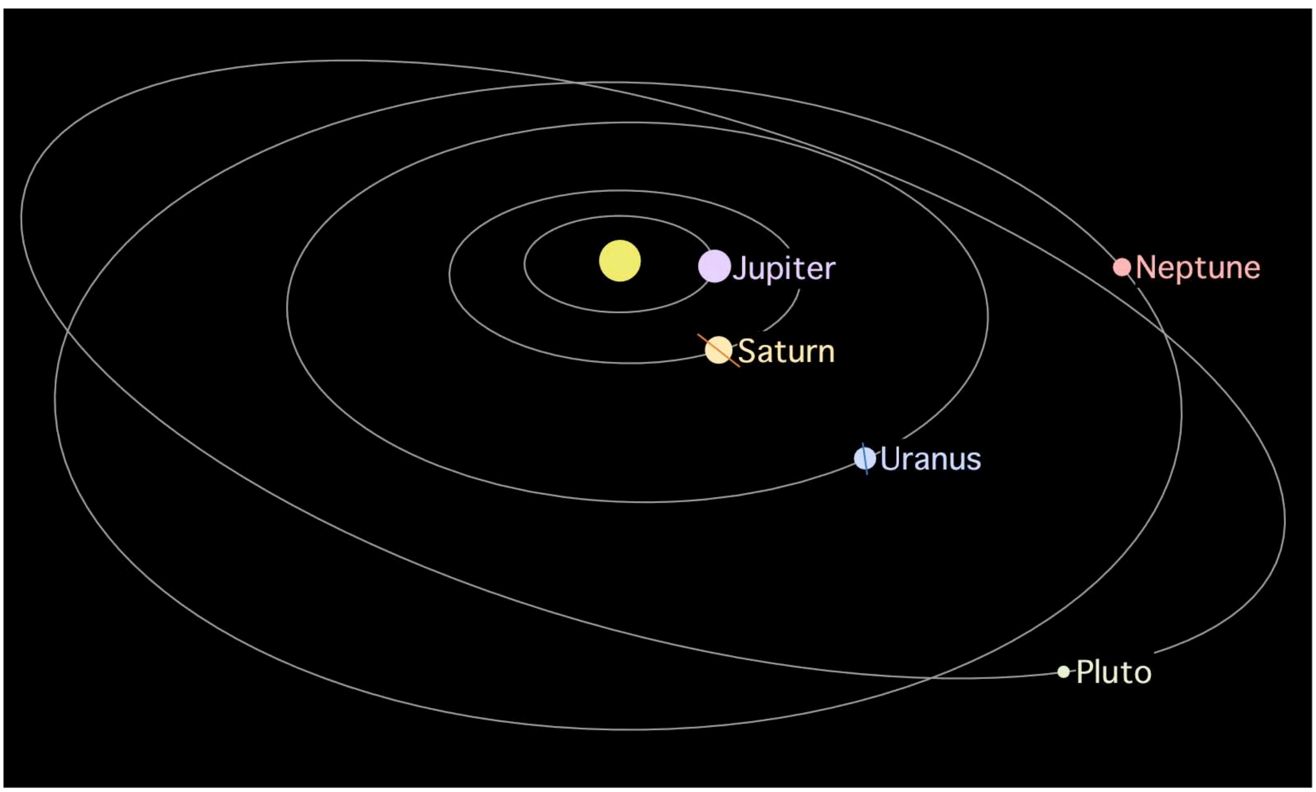


FIGURE 3.9 The outer solar system consists of the dwarf planet Pluto and the planets Jupiter, Saturn, Uranus, and Neptune. *(Image Copyright: Michael Pidwirny)*

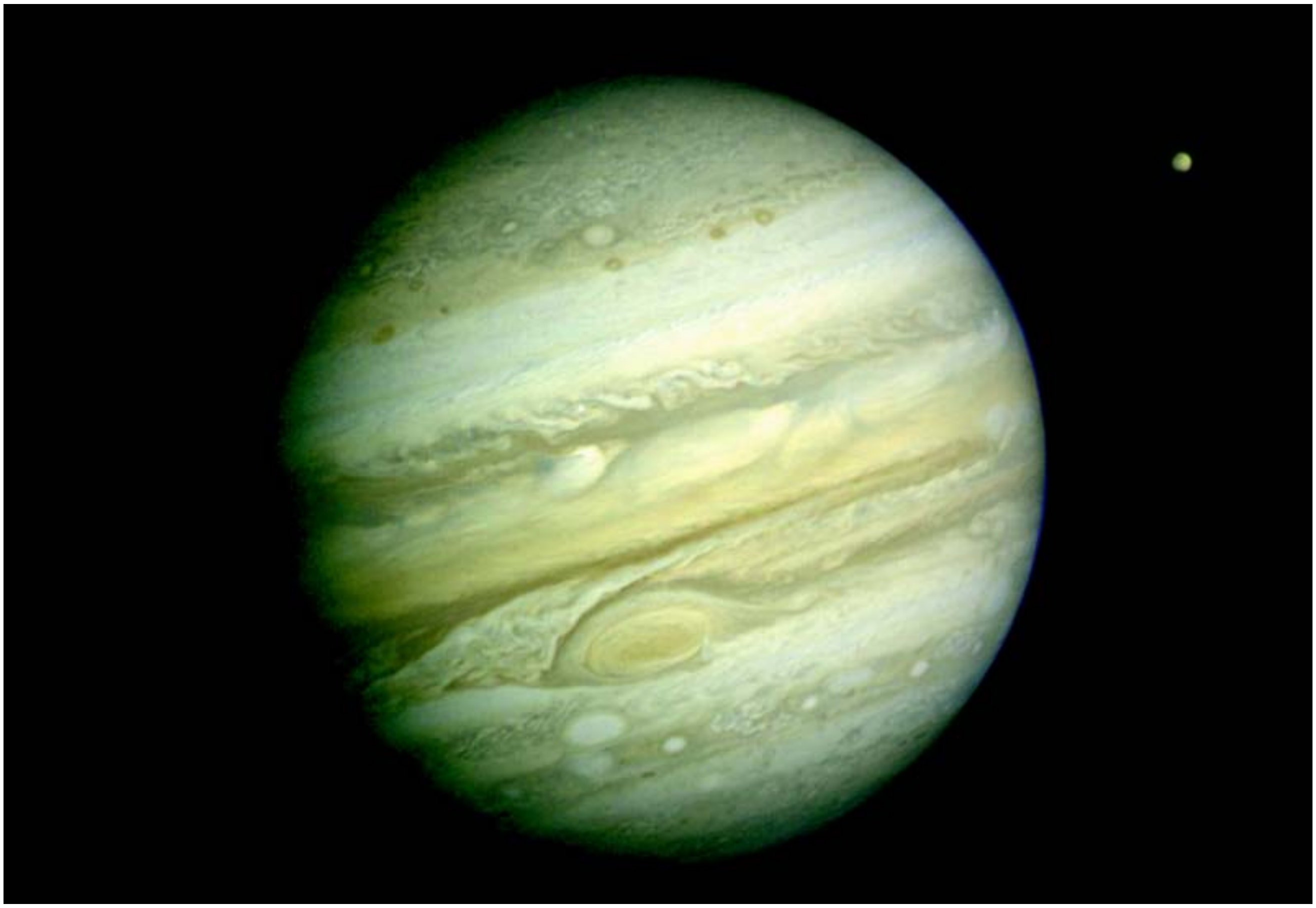


FIGURE 3.10 Voyager 1 took this photo of the gas giant Jupiter and its moon Io on February 1, 1979, at a distance of about 32 million km (20 million mi). In this image, the atmospheric storm known as the Great Red Spot can be seen just below the center of the planet. *(Source: NASA)*

hydrogen layer is the outermost zone composed of a mixture of hydrogen and helium. At the deepest reaches of this zone, these two elements exist as liquids. Further up in this layer the hydrogen and helium become gaseous. The turbulent atmosphere of Jupiter that we see from space represents the very top of this layer.

The Galileo space probe measured the winds moving in Jupiter's upper atmosphere at speeds faster than 600 kph (373 mph). Most Earth-based tornadoes have wind speeds less than 175 kph (109 mph). The Great Red Spot is a hurricane like storm that has been raging in Jupiter's upper atmosphere for more than 400 years. Of the planets in our solar system, Jupiter also has the most rapid rotation. This enormous planet completes one rotation in about 10 hours. Orbiting Jupiter are 63 known satellites, including the four large Galilean moons that are easily visible from a hobby telescope.

Saturn with its rings is considered by many to be one of the most amazing sights in our solar system (**Figure 3.11**). From our most powerful telescopes on Earth we can see seven major rings (Jupiter, Uranus, and Neptune also have rings but they are dark in color and difficult to observe). Close-up images from the Voyager 1 and 2 space probes indicated that the rings of Saturn are composed of ice and rock and organized into thousands of ringlets. The average surface temperature of Saturn's is estimated to be around -125°C (-193°F). Like Jupiter, Saturn is a huge planet composed mainly of hydrogen and helium. Saturn's interior is not as hot as Jupiter's and is estimated to be around 12,000°C (21,600°F). As a result of this internal heat energy, Saturn radiates more energy back to space than it receives from the Sun. The structure of Saturn's interior is also similar to Jupiter's consisting of a rocky core, a liquid metallic hydrogen layer, and a gaseous molecular hydrogen outer layer.

Saturn has more than 30 orbiting satellites. Its largest moon, Titan has an atmosphere composed of mainly nitrogen, 6% argon, and a few percent of methane. These atmospheric conditions are very similar to those of ancient Earth when life was first getting started. Consequently,

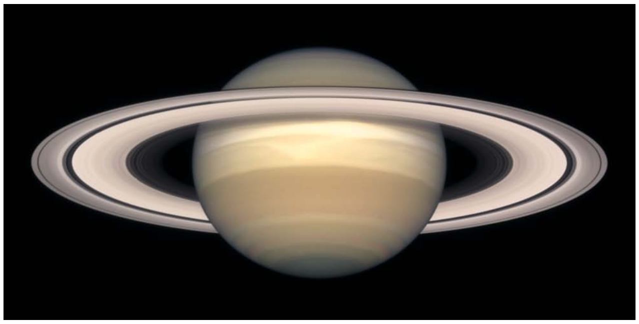


FIGURE 3.11 Saturn in October, 1998. Saturn's equator is tilted relative to its orbit by 27°, very similar to the 23.5° tilt of the Earth. This image shows Saturn during its winter solstice when the North Pole is tilted away from the Sun. *(Source: Hubble Space Telescope)*

scientists speculate that simple forms of life may exist on Titan. No other satellite in our solar system has an atmosphere.

Uranus is the seventh planet from the Sun with an average orbital distance of 2,872 million km or 1,785 million mi (**Figure 3.12**). Because of this great distance from the solar source of light energy, Uranus is a very cold planet with an average temperature of about -193° C (-315°F). Most of the other planets in our solar system spin on an axis nearly perpendicular to the plane of the ecliptic. However, Uranus' rotational axis is almost parallel to the orbital plane around the Sun. Consequently, each of the planet's seasons lasts about 20 years (84 years to complete one revolution around the Sun). Uranus is composed primarily of rock, about 15% hydrogen, a little helium, frozen water, methane, and ammonia. Unlike Jupiter and Saturn, the rocky material is not concentrated in the core of the planet but more or less evenly spread out in its mass. The atmosphere of Uranus is estimated to be about 83% hydrogen, 15% helium, and 2% methane. Over twenty moons are known to orbit Uranus.

The eighth planet from the Sun is called **Neptune** (**Figure 3.13**). Neptune has only been visited by one space probe, Voyager 2 on August 25, 1989. Much of our knowledge about this planet comes from this encounter and observations by the Hubble Space telescope. The last of the gaseous planets, Neptune is probably composed of materials similar to Uranus. Its atmosphere is mainly hydrogen and helium with a small percentage of methane. At the surface of the planet, the atmosphere has a temperature ranging from -153° to -193°C (-346° to -391°F). Neptune's atmospheric winds are the fastest in the solar system, reaching speeds as high as 2000 kph (1240 mph). Several disturbances have been observed in Neptune's active atmosphere. The blue color of the planet

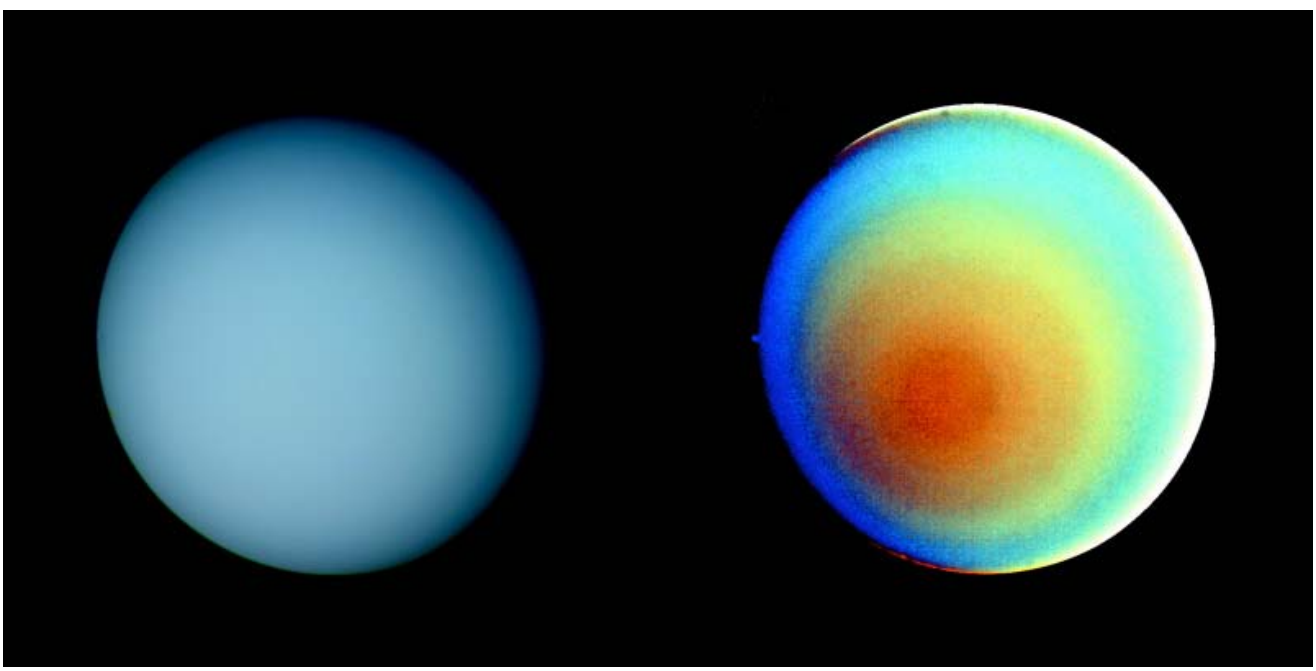


FIGURE 3.12 These two pictures of Uranus, one in true color (left) and the other in false color, were taken by Voyager 2 on January 17, 1986. The false-color image of Uranus reveals a dark polar zone surrounded by a series of progressively lighter concentric bands. One possible explanation for this pattern is that a brownish haze or smog, concentrated over the pole, is arranged into bands by the zonal flow of the upper air winds. *(Source: NASA)*

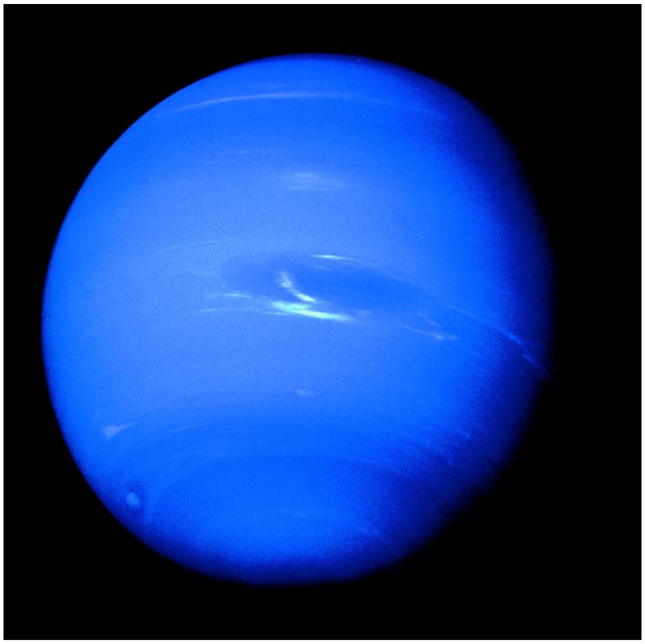


FIGURE 3.13 This image of Neptune was taken by Voyager 2. In the center of the image, we can see Neptune's Great Dark Spot and its companion bright smudge. *(Source: NASA)*

is largely caused by the absorption of red light by methane in the atmosphere. Neptune has 13 known satellites.

Not much is known about the dwarf planet **Pluto** (**Figure 3.14**). Because of its great distance from the Sun, it has not been explored by any remote space probes. We do know that temperatures on Pluto's surface vary from -235°C (-391°F) to -210°C (-346°F). Our best views of the planet come from the Hubble Space Telescope. With this instrument, scientists have been able to measure Pluto's size (and the size of its large moon Charon). Pluto has a highly eccentric orbit that passes inside of Neptune's orbital path for about 20 of the 248 years it takes to complete one revolution around the Sun.

FIGURE 3.14 This Hubble Space Telescope image provided the sharpest view to date of the dwarf planet Pluto and its moon, Charon. This image also allowed astronomers to more accurately measure (to within about 1% error) the diameter of Pluto (2320 km) and Charon (1270 km). *(Source: Hubble Space Telescope)*

MATTER

Elements and Compounds

Matter is the material that makes up living and nonliving things in the Universe. All matter on the Earth is constructed of elements. Chemists have described approximately 115 different **elements**. Each of these unique elements has distinct chemical characteristics. Table 3.2 lists some of the chemical characteristics for 48 common elements found in the Earth's continental crust.

The smallest particle that exhibits the unique chemical characteristics of an element is known as an **atom**. Atoms are composed of yet smaller particles known as protons, neutrons, and electrons (**Figure 3.15**). A **proton** is a subatomic particle that has significant mass and contributes a single positive electrical charge to an atom. **Neutrons** also have significant mass but no electrical charge. **Electrons** are extremely light subatomic particles having a mass that is 1/1840 of a proton. Each electron also has a negative electrical charge.

Protons and neutrons make up the **nucleus** of an atom (**Figure 3.15**). As a result, most of an atom's mass is concentrated in the nucleus. Because protons are positively charged the nucleus has a positive charge equal to the number of these subatomic particles. Electrons are found orbiting outside the nucleus at various distances based on their energy level. The area occupied by the electrons has a negative charge equal to the number of these subatomic particles. If an atom has an equal number of electrons and protons its net electrical charge is zero. If there are more electrons than protons the charge of the atom is negative. Likewise, if there are fewer electrons than protons, the charge of the atom is positive. In both cases, the exact charge is determined by subtracting the number of protons from that of the electrons. For example, 4 protons minus 6 electrons give an atomic charge of -2.

The number of protons found in the nuclei of the different types of elements is unique and is referred to as the **atomic number** (**Table 3.2**). All atoms of a specific element have the same number of protons in their nuclei. **Atomic mass number** is an atom's total number of neutrons and protons. Many elements have unequal numbers of neutrons and protons in their nucleus. An

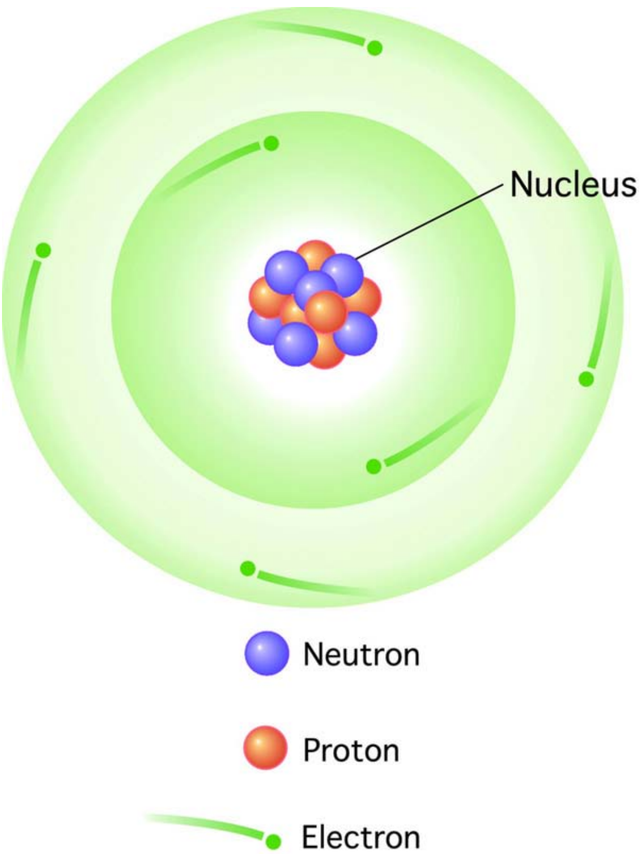


FIGURE 3.15 Graphical representation of a carbon-12 atom. Carbon-12 has a nucleus with six neutrons and six protons. Around this nucleus are two orbital shells containing a total of six fast moving tiny electrons. *(Image Copyright: Michael Pidwirny)*

element's **atomic weight** refers to the total weight of neutrons, protons, and electrons. For example, the atomic weight of aluminum is 26.98 (**Table 3.2**). Atomic number describes the number of protons found in an atom. For example, silver has an atomic number of 47 or 47 protons in its atom (**Table 3.2**). Some elements can have variants containing different numbers of neutrons but similar numbers of protons. We call these variants **isotopes**. Carbon has two isotopes. The most common isotope form is carbon-12, which has 6 protons plus 6 neutrons (**Figure 3.15**). About 99% of the carbon on our planet is of this type. The isotope carbon-13 has 6 protons plus 7 neutrons. Carbon-14 is a rare isotope of carbon containing 6 protons and 8 neutrons. Some isotopes are unstable and their nucleus tends to lose subatomic particles forming an element with a lower atomic mass. This process is known as **radioactive decay**.

Elements can be classified as either being metals, nonmetals, or metalloids (**Table 3.2**). Metals are elements that usually conduct heat and electricity and are shiny. Some metals commonly used by humans include copper, silver, and gold. Nonmetals do not conduct electricity that well and are normally not shiny. Metalloids have characteristics that are in between metals and nonmetals.

When atoms of the same element bond together they construct **molecules**. Atoms of different elements joined together form atomic structures called **compounds** (**Figure 3.16**). Sodium chloride (or table salt) is a compound consisting of sodium (Na^+) and chloride (Cl^-). In nature, it forms as a three-dimensional array of oppositely charged ions (**Figure 3.17**). Many of the Earth's substances have a molecular structure similar to sodium chloride.

Atoms, molecules, or compounds with a net positive or negative charge are called **ions**. Chemists indicate the number of positive or negative charges on an ion using a superscript after the element's symbol. For example, calcium ion has two positive charges and is written as Ca^{2+}. Some common negatively charged ions include nitrate (NO_3^-), sulfate (SO_4^{2-}), and phosphate (PO_4^{3-}). Positive and negative ions are electrically attracted to each other. This mutual attraction allows for the bonding of atoms to occur forming structures of matter that are larger than just one atom.

Properties of Matter

Matter has three physical properties: mass, volume, and density. We often think of an object's **mass** as its weight. This is not entirely correct. Weight is the force caused by the strength of gravity on a mass. If gravity changes weight also changes, but the mass remains the same. So what is mass? Well, we can define mass as a measure of a body's resistance to movement. From this definition, we can suggest that the more massive a body the harder it is to move. The definition also suggests that once an object is in motion, more massive bodies are harder to stop. Mass will be normally measured in this textbook in units of grams (g) or kilograms (kg).

Volume is the second basic property of matter. This property is related to space. Quite simply, volume is a measure of the amount of space an object occupies. It is also important to realize that two objects cannot occupy the same area of space. Volume is primarily measured in this textbook in cubic meters (m^3) or cubic centimeters (cm^3).

Density is a property of matter that is related to both mass and volume. It is defined as the quantity of mass

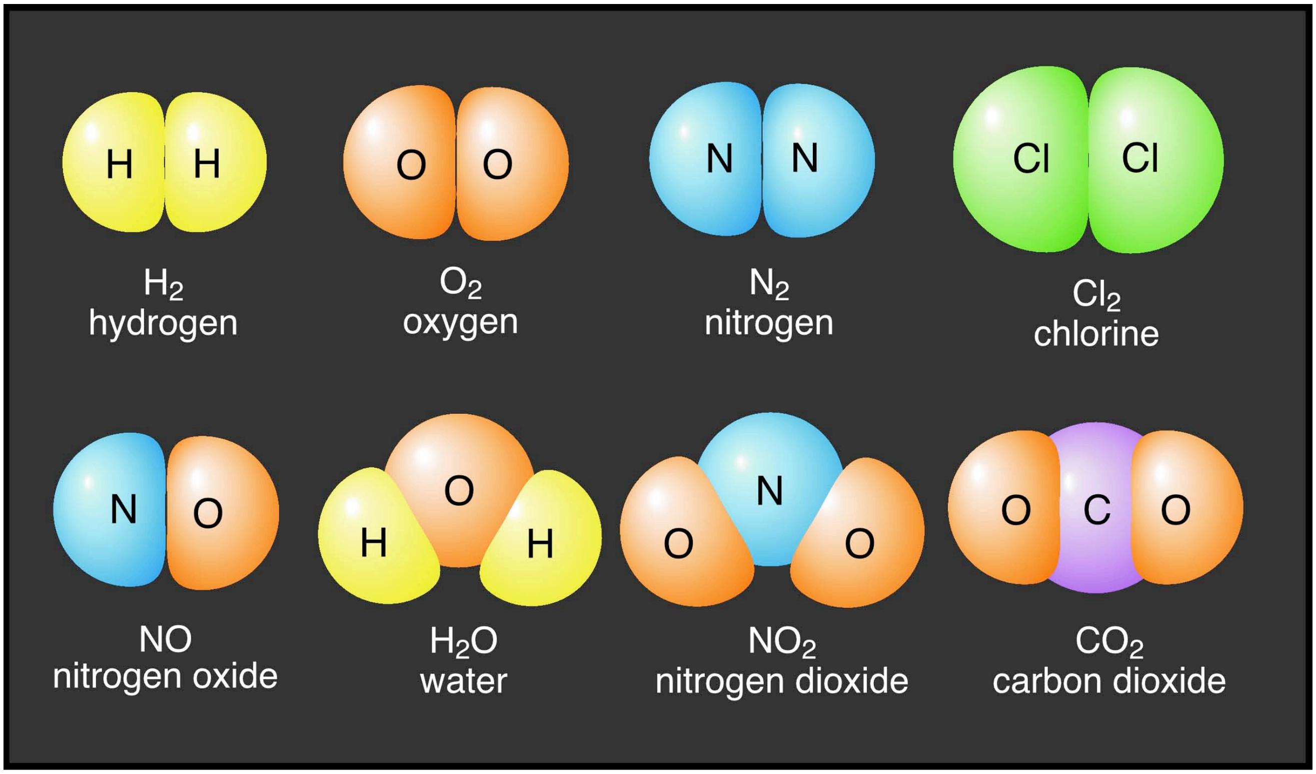


FIGURE 3.16 Some common molecules and compounds. The molecules in the top row bond with each other by sharing electrons. The compounds in the bottom row also share electrons. However, these joins are called ionic bonds. *(Image Copyright: Michael Pidwirny)*

found in a given volume. Common units of density are grams per cubic centimeter (g cm^{-3}) and kilograms per cubic meter (kg m^{-3}).

Phases of Matter

The phases of matter can be classified as solid, liquid, and gas. All forms of matter normally change their phase when specific temperature thresholds are passed. Changes in phase also result in specific alterations in the characteristics of matter (Table 3.3). Let us consider the phase changes of water. If we cool water to a temperature below 0°C (32°F) it freezes into a solid state. In this phase, its molecules become highly organized because of cohesive bonds and take on a geometric shape. If we add heat energy to the ice, this energy will accumulate in its molecules until a threshold is passed causing its phase to become liquid. In the liquid phase, the molecules are still densely packed together and cohesive to each other, but have the ability to freely move or flow. Continuing to add even more heat energy, we reach another threshold where the liquid water transforms into a gas called water vapor. Water vapor contains enough energy to break cohesive bonds between molecules. This energy allows them to

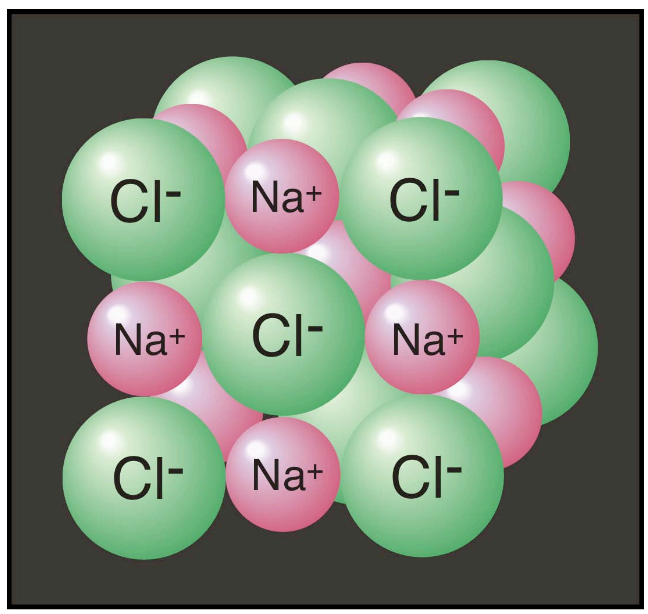


FIGURE 3.17 Sodium chloride is a compound that forms in nature as a highly ordered, three-dimensional network of oppositely charged ions. The bonds that form between the sodium (Na^+) and chloride (Cl^-) ions give this compound great internal strength allowing it to form large crystals. *((Image Copyright: Michael Pidwirny)*

TABLE 2.1 Characteristics of some common elements found in the Earth's continental crust.

Element	Chemical Symbol	Atomic Number	Atomic Mass Number	Atomic Weight	Percent in Continental Crust	Required for all Life	Required For Some Life Forms	Element Type	Free Element Phase
Aluminum	Al	13	27	26.98	8.2300	-	X	Metalloid	Solid
Arsenic	As	33	75	74.92	0.00018	-	-	Metalloid	Solid
Barium	Ba	56	137	137.34	0.0425	-	-	Metal	Solid
Bromine	Br	35	80	79.91	0.00025	-	-	Nonmetal	Liquid
Cadmium	Cd	48	112	112.40	0.00002	-	-	Metal	Solid
Calcium	Ca	20	40	40.08	4.1000	X	-	Metal	Solid
Carbon	C	6	12	12.01	0.0200	X	-	Nonmetal	Solid
Chlorine	Cl	17	35.5	35.45	0.0130	-	X	Nonmetal	Gas
Chromium	Cr	24	52	52.00	0.0100	-	-	Metal	Solid
Cobalt	Co	27	59	58.93	0.0025	-	X	Metal	Solid
Copper	Cu	29	63.5	63.54	0.0055	X	-	Metal	Solid
Fluorine	F	9	19	19.00	0.0625	-	X	Nonmetal	Gas
Gold	Au	79	197	196.97	0.0000004	-	-	Metal	Solid
Hydrogen	H	1	1	1.008	1.4000	X	-	Nonmetal	Gas
Iodine	I	53	127	126.90	0.00005	-	X	Nonmetal	Solid
Iron	Fe	26	56	55.85	5.6000	X	-	Metal	Solid
Lead	Pb	82	207	207.19	0.00125	-	-	Metal	Solid
Lithium	Li	3	6	6.94	0.0020	-	-	Metal	Solid
Magnesium	Mg	12	24	24.31	2.3000	X	-	Metal	Solid
Manganese	Mn	25	55	54.94	0.0950	X	-	Metal	Solid
Mercury	Hg	80	201	200.59	0.000008	-	-	Metal	Liquid
Molybdenum	Mo	42	96	95.94	0.00015	X	-	Metal	Solid
Nickel	Ni	28	59	58.71	0.0075	-	-	Metal	Solid
Nitrogen	N	7	14	14.01	0.0020	X	-	Nonmetal	Gas
Oxygen	O	8	16	16.00	46.4000	X	-	Nonmetal	Gas
Phosphorus	P	15	31	30.97	0.1050	X	-	Nonmetal	Never Free
Platinum	Pt	78	195	195.09	0.0000005	-	-	Metal	Solid
Potassium	K	19	39	39.10	2.1000	X	-	Metal	Solid
Selenium	Se	34	79	78.96	0.000005	-	X	Nonmetal	Solid
Silicon	Si	14	28	28.09	28.2000	-	-	Metalloid	Solid
Silver	Ag	47	108	107.87	0.000007	-	-	Metal	Solid
Sodium	Na	11	23	22.99	2.4000	-	X	Metal	Solid
Sulfur	S	16	32	32.06	0.0260	X	-	Nonmetal	Solid
Tin	Sn	50	119	118.69	0.00020	-	-	Metal	Solid
Titanium	Ti	22	48	47.90	0.5700	-	-	Metal	Solid
Tungsten	W	74	184	183.85	0.00015	-	-	Metal	Solid
Uranium	U	92	238	238.03	0.00027	-	-	-	Solid
Vanadium	V	23	51	50.94	0.0135	-	X	Metal	Solid
Zinc	Zn	30	65	65.37	0.0070	X	-	Metal	Solid

move even more freely so that they can completely fill the space.

Types of Matter

We can suggest that there are two types of matter: organic and inorganic. Compounds and molecules constructed in living tissues are commonly called **organic**. Forms of matter not produced by living things are termed **inorganic**.

There are four general categories of organic compounds: lipids, carbohydrates, proteins, and nucleic acids. **Lipids** are organic molecules composed of carbon atoms that have two hydrogen atoms attached. They are commonly known as fats and oils. Lipids also belong to the family of molecules known as hydrocarbons. **Carbohydrates** are composed of carbon, oxygen, and hydrogen atoms. Some examples are sugars, starch, and cellulose. **Proteins** are organic compounds that are made primarily of carbon, hydrogen, nitrogen, and some other minor elements that are arranged into 20 different compounds known as **amino acids**. Finally, **nucleic acids** are composed primarily of different combinations of carbon, hydrogen, nitrogen, oxygen, and phosphorus. They are very complex compounds being created by the atomic linking of thousands of individual atoms. **DNA** or **deoxyribonucleic acid**, the genetic blueprint of life, is an example of a nucleic acid.

Cellular Structure of Life

All organisms are composed of one or more of cells. **Cells** are the smallest self-functioning unit found in living organisms. Cells are also where the processes of metabolism and heredity occur in an organism. The cellular division of a previously existing cell forms new cells. Biologists have differentiated two basic types of cells in organisms. Bacteria, archaea, and cyanobacteria have cells that are quite uncomplicated in terms of structure and function. Quite simply, they lack internal organization. These cells are commonly known as **prokaryotes** (**Figure 3.18**).

The cells of plants and animals are more complex than those of bacteria, archaea, and cyanobacteria. We identify these cells as being **eukaryotes**. Eukaryotic cells have a membrane-enclosed nucleus that contains the organism's DNA. Eukaryotic cells are generally larger than prokaryote cells. Prokaryotic cells range in size from about 1 to 10 µm (micrometers). White blood cells of mammals are some of the smallest eukaryotic cells with a diameter between 3 to 4 µm. Ostrich ova are very large cells with a diameter of about 100 µm.

Plant and animal cells also contain a variety of membrane-bound structures known as **organelles**. Organelles are cellular structures that carry out a distinct function. Within the organelles enzymes, a type of protein, are used to facilitate and regulate various chemical reactions. **Figure 3.19** describes the various structures found in typical plant and animal cells. **Table 3.4** describes the function of a variety of cell structures including many organelles.

Cells can also be classified according to how they obtain their energy. Some cells have the ability to use light or chemical energy found in the outside environment to manufacture their own sugars, fats, and proteins. We call these types of cells **autotrophs**. All species of plants and a few species of bacteria use sunlight and the process of

TABLE 3.3 Characteristics of matter in different states of phase.

Phase	Relative Temperature	Order	Shape	Attractive Forces	Comments
Solid	Low	High	Definite	Strong	Atoms form regular geometric patterns called crystal lattices.
Liquid	Medium	Medium	Conforms to the shape its sitting in	Medium	Atoms are still attracted to each other but have the ability to move relative to each other (flow).
Gas	High	Low	Fills open space	Weak	Atoms move about randomly and maintain a distance between each other.

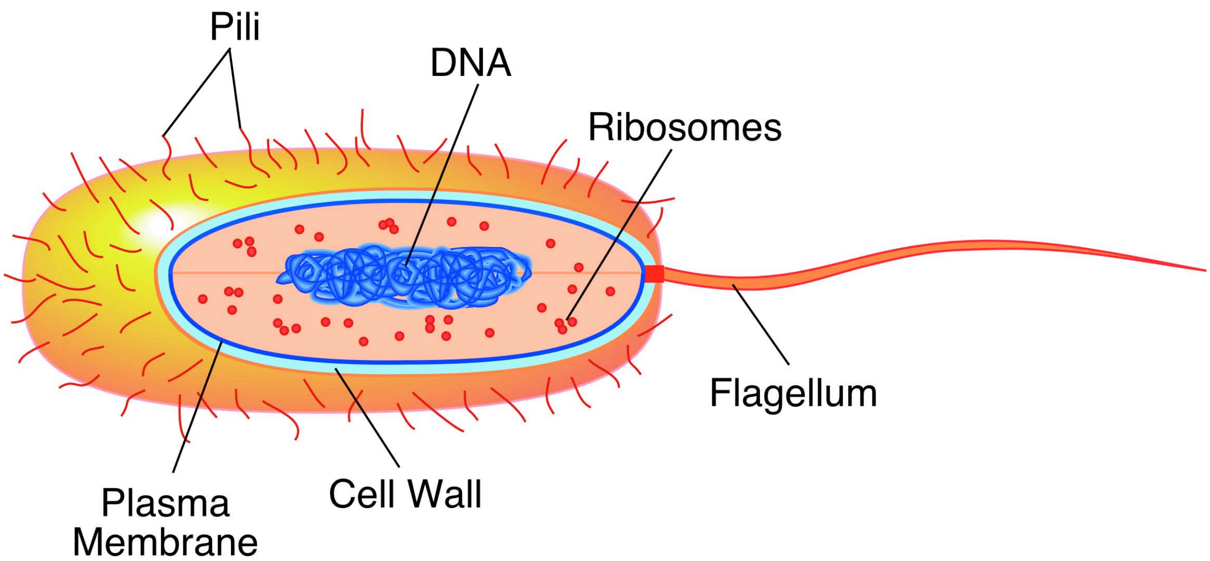


FIGURE 3.18 Typical features of a prokaryote cell. Prokaryote cells are about 1 to 10 micrometers in size. Prokaryote cells are encased by rigid cell wall and a plasma membrane. Within the cell, the two most obvious structures are ribosomes and DNA. In prokaryote cells, DNA is not found inside a membrane. Many prokaryote cells also have a flagellum that is used for movement. *(Image Copyright: Michael Pidwirny)*

photosynthesis to obtain their energy. Some bacteria breakdown molecules found in the environment to release chemical energy to sustain their life. Cells (and organisms) can also obtain their energy by consuming other cells. These cells are called **heterotrophs**. Heterotrophs include most types of bacteria and all of the animal and fungi species.

Some organisms consist of just one cell. All species of bacteria and archaea are unicellular. Some algae, fungi, and protista can also exist as single celled life. Most organisms found on our planet exist in a multi-cellular form. Within multi-cellular organisms, groups of cells can become specialized to carry out a specific function. We call such a functional group of cells a **tissue**. Some examples of tissues include muscle tissue and nervous tissue, which is commonly found in animals. An **organ** is a structure composed of several different types of tissues. Organs also have a specific structure and a particular function.

ENERGY

Energy is simply defined by scientists as the capacity for doing work. Albert Einstein suggested in the early 20th century that energy and matter are related to each other at the atomic level. Einstein theorized that it should be possible to convert matter into energy. From Einstein's theories, scientists were able to harness the energy of matter beginning in the 1940s through nuclear fission. **Nuclear fission** releases vast amounts of heat energy by breaking the atomic bonds between atoms. The most spectacular example of this process is the nuclear explosion produced by an atomic bomb. A more peaceful example of our use of this fact of nature is the production of electricity from controlled fission reactions in nuclear reactors.

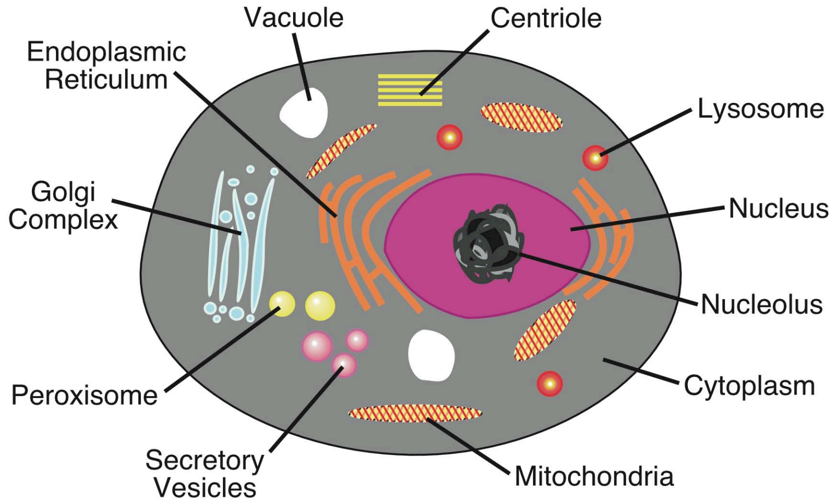
Einstein also suggested that it should be possible to transform energy into matter. In 1997, researchers at Stanford University's Linear Accelerator Center successfully converted energy into matter (Burke, et al., 1997). This feat was accomplished by using lasers and incredibly strong electromagnetic fields to change ordinary light into matter.

Energy and matter are also associated to each other at much larger scales of nature. Later on in this chapter, we will examine how solar radiation provides the energy to create the matter that makes up organisms. Organisms use some of this matter to power their metabolism.

TYPES OF ENERGY

Energy comes in a variety of forms. The simplest definition of the types of energy suggests that two forms exist: kinetic energy and potential energy. **Kinetic energy**

Animal Cell



Plant Cell

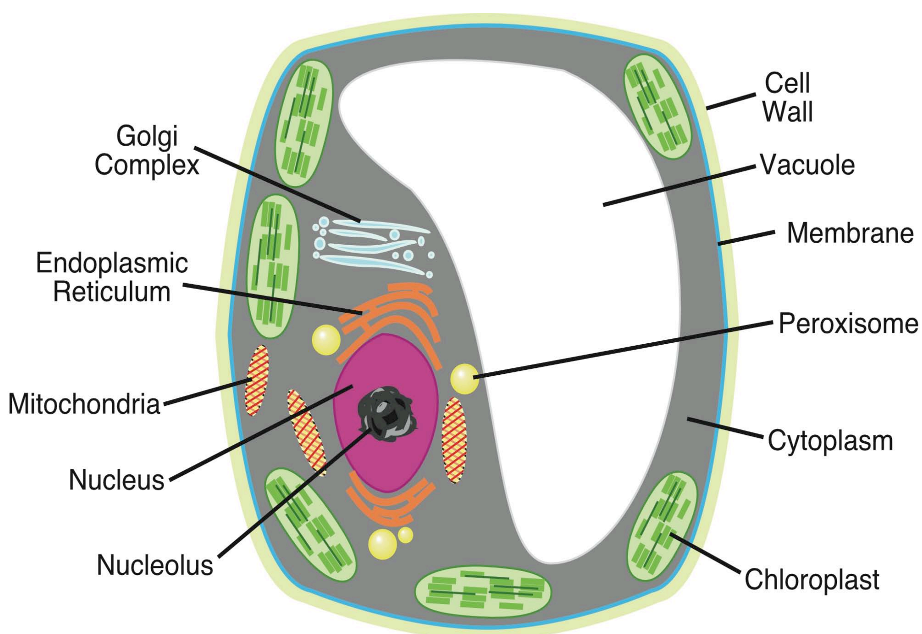


FIGURE 3.19 Typical features of animal and plant cells. Plant cells differ from animal cells in the following ways: they have a cell wall, chloroplasts, they do not contain lysosomes, and they often have a large central vacuole. *(Image Copyright: Michael Pidwirny)*

TABLE 3.4 Description and function of common cell structures.

Structure	Description	Function
Cell Wall	Outer layer on a cell composed of cellulose or other complex carbohydrates.	Helps to support and protect the cell.
Plasma Membrane	A layer composed of lipids and proteins that controls the permeability of the cell to water and dissolved substances.	Regulates the movement of material into and out of the cell.
Flagellum (Flagella pl.)	Threadlike organelle that extends from the surface of the cell. Found in both prokaryotes and eukaryotes.	Used for movement of the cell or to move fluids over the cell's surface for absorption.
Ribosomes	Tiny, complex structures composed of protein and RNA. Often attached to endoplasmic reticulum.	Ribosomes are involved in protein synthesis.
Endoplasmic Reticulum	Extensive system of internal membranes.	Forms compartments to isolate cell substances.
Nucleus	Double membrane structure that encases chromosomes.	Control center of the cell that directs protein synthesis and cell reproduction.
Chloroplasts	Elongated structures with vesicles containing chlorophyll.	Site of photosynthesis.
Chromosomes	Long strands of DNA.	Store hereditary information.
Nucleolus	Aggregations of rRNA and ribosomal proteins.	Area were ribosomes are manufactured.
Golgi Complex	Flattened stacks of membranes.	Used in the collection, packaging, and distribution of synthesized molecules.
Peroxisomes	Membrane confined spherical body about 0.2 to 0.5 micrometers in diameter.	Formed by the endoplasmic reticulum. Converts fats into carbohydrates. Detoxifies potentially harmful oxidants.
Lysosomes	Membrane confined spherical body about 0.2 to 0.5 micrometers in diameter.	Formed by the golgi complex. Contains digestive enzymes for braking down old cellular components.
Centrioles	Long hollow tubes composed of protein. Not found in plant cells.	Influence cell shape, move chromosomes during reproductive division, and are the internal structure for flagellum.
Secretory Vesicles	Membrane enclosed sack created at the golgi complex.	These structures contain cell secretions. The secretory vesicles are then transported to the cell surface where they are release to the environment outside the cell.
Vacuole	Voids within the cytoplasm. Quite large in plant cells.	Used to store water and waste products.
Cytoplasm	Semi-fluid mixture that occupies most of the cell's interior. Contains sugars, amino acids, and proteins. Also, contains a protein fiber network.	Medium in which organelles and other structures exist in. Fiber network support the shape of the cell and anchor organelles to fixed positions.
Mitochondria	Elongated structures about 1 to 3 micrometers long. Resemble aerobic bacteria.	Structure which converts sugar into energy through oxidation.

is the energy due to motion. A rock falling from a cliff, a bee in flight, the blowing leaves of trees, and water following over a waterfall are all examples of kinetic energy. **Potential energy** is the energy stored by an object that can be potentially transformed into another form of energy. Water stored behind a dam, the chemical energy of the food we consume, and the gasoline that we putting in our cars are all examples of potential energy. Conversion of this energy occurs when food is used by an organism to energize its metabolism, or when the water in the dam flows through turbines to produce electricity from motion, or when the gasoline is used in an engine to produce motion from combustion.

Some other forms of energy include heat, electricity, sound, energy of chemical reactions, magnetic attraction, energy of atomic reactions, and light. Definitions for a few of these types of energy are as follows:

Electromagnetic Radiation or **Radiation** - is the emission of energy from a material object in the form of electromagnetic waves and photons.

Atomic Energy - is the energy released from an atomic nucleus because of a change in its subatomic mass.

Heat Energy - is a form of energy created by the combined internal motion of atoms in a substance.

Chemical Energy - is the energy consumed or produced through chemical reactions.

Electrical Energy - is the energy produced from the force between two objects having the physical property of electrical charge.

On Earth, there are fundamentally three ways in which energy can be transferred from one place to another: conduction, convection, and radiation. **Conduction** is the transfer of heat energy directly from atom to atom along a temperature gradient. Conduction can operate in a gas, liquid, or solid. **Convection** is the transfer of heat energy by the vertical movement of a mass of gas or liquid (horizontal transfer is called **advection**). Radiation is the only means of energy transfer that can occur across the empty void of outer space. We will discuss these processes again in much greater detail at the end of this chapter.

Measurement of Energy

In the previous sections, we began developing an operational concept of energy. We now must learn how energy is measured and quantified using a standard set of units. Worldwide, two systems of units of measurement are often used today: the Metric System (*Systeme International*) and the British System. The units of energy described in these systems are derived from a technical definition of energy used by physicists. This definition of energy can be represented by the following relationship:

WORK = FORCE x DISTANCE

Similar to the definition given in the previous section, physicists view energy as the ability to do work. However, they define work as a force applied to some form of matter (object) multiplied by the distance that this object travels. Physicists commonly describe force with a unit of measurement known as a **Newton** (N). This unit of measurement is named after Sir Isaac Newton. A Newton is equal to the force needed to accelerate (move) a mass weighing one kilogram one meter in one second in a vacuum with no friction. The work (or energy) needed to move an object with the force of one Newton over a distance of one meter per second squared (the increase in speed that is attained with each additional second) is called a **joule** (J).

Two other energy measurement units that you will come across in this textbook are calorie and watt. A **calorie** (cal) is equal to the amount of heat required to raise one gram of pure water from 14.5 to 15.5°C at standard atmospheric pressure. One calorie is equal to 4.1855 joules. A kilocalorie (kcal) is equal to 1000 calories.

A **watt** (W) is a metric unit of measurement of the intensity of radiation normally measured over a square meter of surface area (watts per meter squared or Wm^{-2}). A watt differs from calories and joules in that it measures **power** or the rate of work. Power can be defined by the following equation:

POWER = WORK/TIME

One watt is equal to one joule of work done per second. A kilowatt (kW) is equal to 1000 watts.

Energy, Temperature, and Heat

So far we have learned that energy can take on many forms. One important form of energy, relative to life on Earth, is kinetic energy. The amount of kinetic energy that a body possesses is dependent on the speed of its motion and its mass. At the atomic scale, the kinetic energy of a body is determined by the heat energy stored in its atoms and molecules.

Kinetic energy is also related to the concept of temperature. **Temperature** is defined as the measure of the average kinetic energy found in the atoms and molecules of a substance. The higher the temperature, the faster these particles of matter move. When temperature is lowered, the atomic motion slows until it completely stops at a temperature of -273.15°C (-459.67°F). This temperature is called **absolute zero**.

The difference between heat and temperature should become more obvious in the following example. This example will also show that a relationship exists between heat energy and mass. Let us compare the heating of two different masses of water (**Table 3.5**). One mass has a weight of 5 g (gram), while the other is 25 g. If the temperature of both masses is raised from 20 to 25°C, the larger mass of water will require five times more heat energy for this increase in temperature. This large mass would also contain five times more stored heat energy.

Heat can also be defined as energy in the process of being transferred from one object to another because of a temperature difference. The spatial distribution of temperature in a substance determines the direction and rate of heat flow. Heat always flows from warmer to colder areas. The rate or speed at which heat flows is controlled by the temperature gradient that exists over space within a body that is composed of the same substance (**Figure 3.20**). Thus, the steeper the gradient the more rapid the heat flow will be.

A number of measurement scales have been invented to quantify temperature. The most commonly used scales are the Celsius, Fahrenheit, and Kelvin systems. Swedish astronomer Anders Celsius developed the Celsius scale in 1742. In this scale, the melting point of ice was given a value of 0, the boiling point of water is 100, and absolute zero is -273. The Fahrenheit system is a temperature scale that is used exclusively in the United States. Created by German physicist Gabriel Fahrenheit in 1714, this scale assigns a value of 32 for the melting point of ice, 212 for the value at which water boils, and absolute zero has a temperature of -460. In 1848, British physicist Lord Kelvin proposed the Kelvin scale. Scientists often use this system because its temperature readings begin at absolute zero and due to the fact that the scale is proportional to the amount of heat energy actually found in an object. The Kelvin scale assigns a value of 273 for the melting temperature of ice, while the boiling point of water occurs at 373.

TABLE 3.5 Heat energy required to raise two different quantities of water 5° Celsius.

Mass of the Water	Starting Temperature	Ending Temperature	Heat Required
5 g	20°C	25°C	25 Calories
25 g	20°C	25°C	125 Calories

Some other important definitions related to energy, temperature, and heat are heat capacity, specific heat, sensible heat, and latent heat. The **heat capacity** is the amount of heat energy absorbed by a substance associated to its corresponding temperature increase. **Specific heat** is equivalent to the heat capacity of a unit mass of a substance or the heat needed to raise the temperature of one gram (g) of a substance 1°C (**Table 3.6**). Water requires about 4 to 5 times more heat energy to raise its temperature when compared to an equal mass of most types of solid matter. Sensible heat is heat that we can

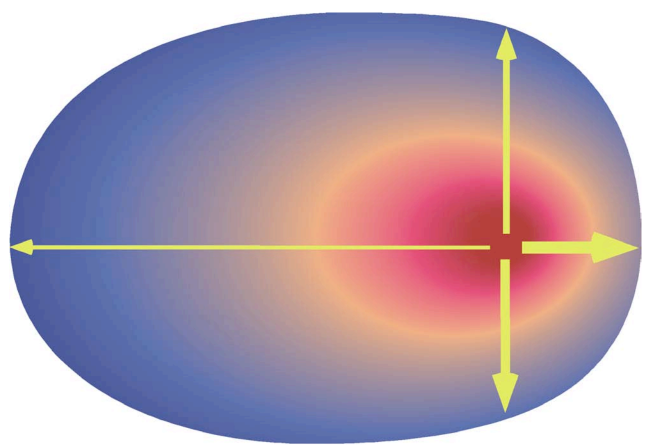


FIGURE 3.20 The following diagram shows the temperature gradient in an object composed of a similar substance. At the extremes, red is hot and blue is cold. The four arrows show the relative speed of the heat flow through this object to its edge. The short wide arrow indicates a steep temperature gradient and relatively fast heat flow. The long narrow arrow indicates a shallow temperature gradient and relatively slow heat flow. *(Image Copyright: Michael Pidwirny)*

TABLE 3.6 Specific heat of some substances for a 1°C rise in temperature.

Substance	Heat Energy Joules / gram / °C
Gold	0.13
Mercury	0.14
Copper	0.39
Iron	0.46
Salt (NaCl)	0.86
Aluminum	0.87
Air	1.01
Ice (0°C)	2.03
Water	4.18

sense. A thermometer can be used to measure this form of heat. **Latent heat** is the energy needed to change a substance to a higher state of matter. This same energy is released from the substance when the change of state (or phase) is reversed. **Figure 3.21** describes the various exchanges of latent heat involved with one gram of water.

LAWS OF THERMODYNAMICS

The field of thermodynamics studies the behavior of energy flow in natural systems. From this study, a number of physical laws have been established. The laws of thermodynamics describe some of the fundamental truths of thermodynamics observed in our Universe. Understanding these laws is important to students of physical geography because many of the processes studied involve the flow of energy.

First Law of Thermodynamics

The first law of thermodynamics is often called the Law of Conservation of Energy. This law suggests that energy can be transferred from one system to another in many different forms. Also, it cannot be created or destroyed. Thus, the total amount of energy available in the Universe is constant. Einstein's famous equation (written below) describes the relationship between energy and matter:

$$E = mc^2$$

In the equation above, energy (E) is equal to matter (m) times the square of a constant (c). Einstein suggested that

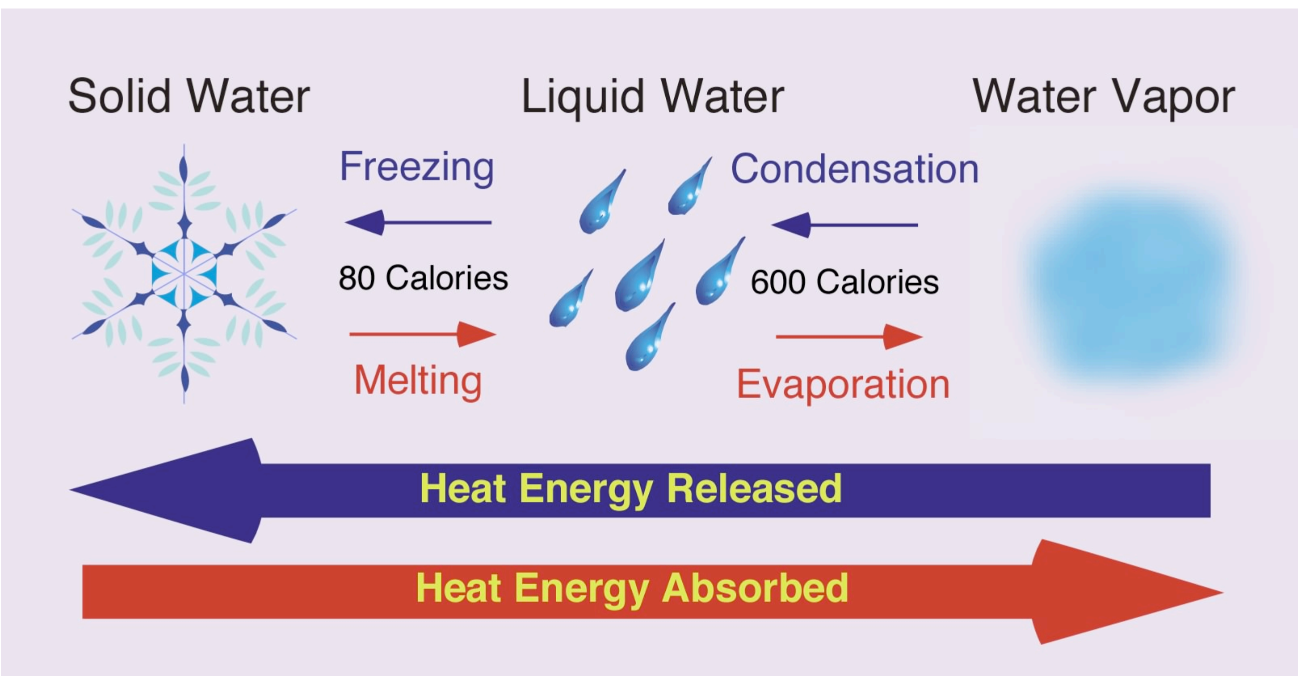


FIGURE 3.21 Latent heat exchanges of energy associated with the phase changes of 1 gram water. *(Image Copyright: Michael Pidwirny)*

energy and matter are interchangeable. His equation also suggests that the quantity of energy and matter in the Universe is fixed.

Second Law of Thermodynamics

Heat cannot be transfer from a colder to a hotter body. As a result of this fact, natural processes that involve energy transfer must have one direction, and all natural processes are irreversible. This law also predicts that the entropy of an isolated system always increases with time. **Entropy** is the measure of the disorder or randomness of energy and matter in a system. Because of the second law of thermodynamics both energy and matter in the Universe are becoming less useful as time goes on. Perfect order in the Universe occurred the instant after the Big Bang when energy and matter and all of the forces of the Universe were unified.

Third Law of Thermodynamics

The third law of thermodynamics states that if all the thermal motion of molecules (kinetic energy) could be removed, a state called absolute zero would occur. Absolute zero results in a temperature of 0 K (Kelvin) (-273.15°C or -459.67°F). The Universe will attain absolute zero when all energy and matter is randomly distributed across space. Scientists estimate that the temperature of the Universe (and space) one minute after the Big Bang was about 100 million K. After another 100 years, the ambient temperature of Universe had dropped to 100,000 K because of the expansion of space and the wider distribution of matter and energy. The current temperature of the now immense voids of space is about 2.7 K (-270.5°C or -454.8°F).

TABLE 3.7 Thermal conductivity of various substances - The higher the value the faster heat travels in the substance by conduction.

Substance	Thermal Conductivity at 25° C Unless Otherwise Stated (Watts / meter / °C)
Air	0.024
Glass Wool Insulation	0.04
Wood	0.04 – 0.4
Dry Soil	0.25
Water	0.60
Snow (< 0°C)	0.05 – 0.25
Ice (0°C)	2.18
Granite	1.7 – 4.0
Iron	80
Aluminum	250
Copper	401
Silver	429
Diamond	900 - 2320

ENERGY TRANSFER ON OUR PLANET

Conduction, Convection, and Radiation

In nonliving systems, energy moves about the Earth via three processes: conduction, convection, and radiation. Both conduction and convection involve the movement of energy through the spatial transfer of thermal heat contained in the atoms and molecules of matter. We are all familiar with the conduction. This is the process that helps cook our food in frying pans. Conduction involves transfer of heat through a substance along a gradient of molecules that are in contact with each other. It can occur in all three phases of matter: gas, liquid, or solid. Conduction ends when the heat energy stored in these molecules becomes the same due to heat flow. In the process of cooking, we turn on a stove's burner to create heat from the burning of natural gas. This heat is then passed on to the metallic molecules of the pan sitting on the surface of the element. The heat energy in the metal of the pan is then transferred to the food above. The speed or rate at which heat energy is transferred by conduction through a substance is determined by its **thermal conductivity** (**Table 3.7**). Some substances, like most metals, conduct heat quite readily. Objects that are poor conductors of heat are called insulators. Air is an example of a good insulator.

Most of the vertical heat flow in the Earth's atmosphere and oceans is the result of convection. Convection is the transfer of heat energy by circulation or mass motions of matter inside a substance. This process can only occur in matter that is in a liquid or gaseous state. The actual movement of matter by this process is the result of spatial differences in a substance's density. Applying heat locally to a mass of matter causes its molecules to become more active and decreases their density. This heated mass then becomes buoyant because the matter surrounding it has a higher density. As the mass floats, the void created beneath it is filled by the flow of the surrounding more dense matter. Another way to picture this process is to consider how we get hot air balloons to float in the atmosphere. The process begins by filling the balloon with air heated with a burner. The heated less dense air then causes the balloon to convectively lift in the cool more dense atmosphere.

Early in this chapter, we defined electromagnetic radiation as the emission of energy from an object in the form of electromagnetic waves. Most of the energy that drives the Earth's various systems comes originally from the Sun's radiant emissions. This energy is beamed from the Sun's surface to the Earth via electromagnetic waves that travel at the speed of light and release heat energy when absorbed by an object. Note that electromagnetic waves do not require matter to function and they can travel across the vacuum of space. Conduction and convection do not operate in space. If you live in a place that experiences winter you may have noticed the warming effects of radiation. If we face the Sun on a cold winter day we can feel our skin heating up despite the frigid air temperatures. The warmth that we feel is created because the Sun's electromagnetic energy is absorbed and converted into heat energy on the surface of our skin. We will learn some more interesting details about radiation in the next chapter.

It is important to note that the processes of conduction, convection, and radiation often occur in tandem. This fact is best illustrated with the heating of our planet's atmosphere. The original source of the heat energy found in the atmosphere is solar radiation. This energy travels from the Sun through the transparent atmosphere to the ground surface. At the ground surface, the radiation is absorbed and converted from electromagnetic waves into heat energy. This process causes the temperature of the ground to rise as heat builds up. The heat energy is then transferred by conduction to a thin layer of air next to the ground surface. Only a thin layer of atmosphere is involved in the conduction process because of air's poor ability to conduct heat. However, air is quite effective in transferring heat energy by way of convection. Convection begins when the atmosphere heated near the ground surface becomes warm enough to develop free-floating parcels of air. These buoyant parcels of air are sometimes called thermals. The development of the thermals stops when the intensity of the solar radiation drops off in the late afternoon because of low Sun angles.

Energy Transfer and Life

In the biosphere, the production and consumption of energy at the cellular level is mainly controlled by two processes: photosynthesis and cellular respiration. Through these two processes organisms are able to obtain all of the energy they require for their activities.

Photosynthesis

Plants and some other organisms can capture the electromagnetic energy from the Sun by a chemical process called **photosynthesis**. In plants, photosynthesis takes place in cellular organelles called **chloroplasts**. The chemical reaction for the photosynthetic process can be described by the following simple equation:

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

The products of photosynthesis are the carbohydrate glucose ($C_6H_{12}O_6$) and oxygen (O_2), which is released into the atmosphere (**Figure 3.22**). Glucose is produced by chemically combining carbon dioxide (CO_2) and water (H_2O) with the energy from sunlight. Plants can convert the glucose created in photosynthesis into starch for storage or into specialized carbohydrates such as cellulose. The glucose molecules can also be combined with other nutrients such as nitrogen, phosphorus, and sulfur, to build complex molecules such as proteins and nucleic acids.

Animals cannot produce their own energy via photosynthesis. Instead, they capture their energy by the consumption and assimilation of the biomass of plants or other animals. Thus, animals get the energy they need for maintenance of their body's tissues, growth, and reproduction from photosynthetic organisms.

Cellular Respiration

Energy can be released from glucose through chemical oxidation. In living organisms, this process is called **cellular respiration**. Cellular respiration occurs in both plants and animals in a cellular organelle called the **mitochondria**. In most organisms, respiration releases all the energy required for metabolic processes. The chemical reaction for respiration can be described by the following simple equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy released}$$

As we can see from the equation, there are three products to this process: carbon dioxide (CO_2), water (H_2O), and

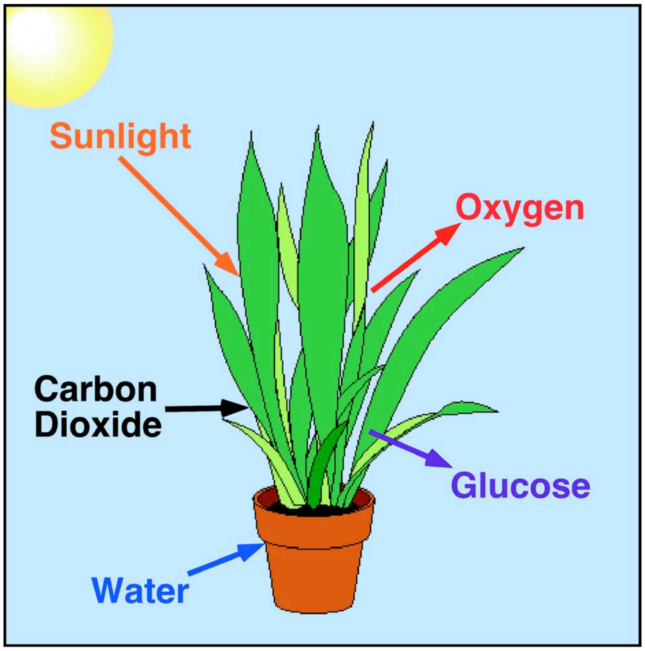


FIGURE 3.22 The process of photosynthesis takes water, carbon dioxide, and the energy of sunlight to produce oxygen and the organic molecule glucose. This chemical process occurs in the chloroplasts of plants. The energy contained in glucose can be later released for metabolism by the process of cellular respiration. *(Image Copyright: Michael Pidwirny)*

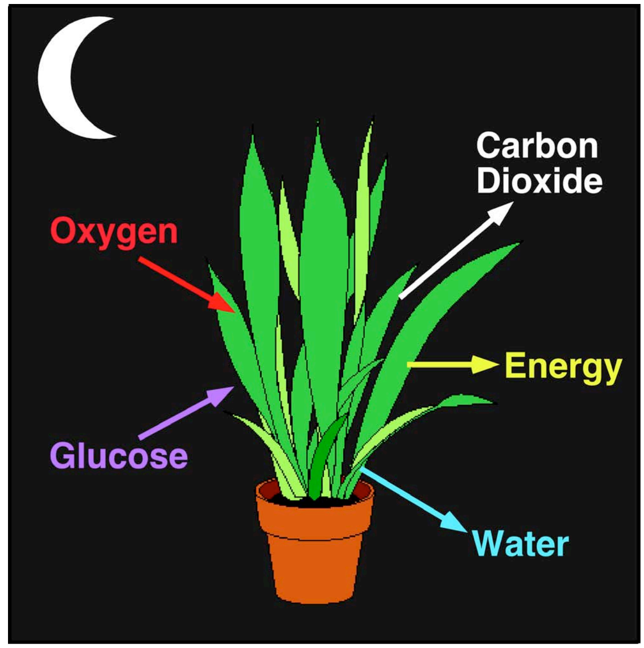


FIGURE 3.23 Cellular respiration releases the energy stored in the organic molecule glucose. This process occurs in the mitochondria found in the cells of organisms. Cellular respiration also requires oxygen and its other products include carbon dioxide and water. *(Image Copyright: Michael Pidwirny)*

energy for metabolism (**Figure 3.23**). Note that the equation for respiration is the reverse of the equation for photosynthesis.

CHAPTER SUMMARY

- The Big Bang theory is presented as a model to explain the origin, history, and future of the Universe.
- Most cosmologists believe matter, energy, space, and time in our Universe were created from the Big Bang about 13.7 billion years ago. Ever since this explosion, the Universe has been expanding at the speed of light. Verification of this theory is based on four pieces of circumstantial evidence.
- A number of structures exist in the Universe. Some of the more important structures are stars, galaxies, and solar systems.
- A star is a celestial body that is able to generate its own light from nuclear fusion.
- A galaxy is a concentration of billions of stars in a region of space. Our Sun exists in a galaxy known as the Milky Way.
- Orbiting most stars are planets, dwarf planets, satellites, asteroids, and comets. The space occupied by these objects around a star is known as a solar system.
- About 5 billion years ago our solar system formed around the Sun. Of the planets and dwarf planet found in our solar system, each of these bodies varies in terms of a number of characteristics.
- Only one planet, Earth, has the right combination of characteristics to allow for the existence of life.
- Matter is the stuff that makes up the Universe.
- All matter is constructed of elements. Each element has a unique atomic structure that creates its specific chemical characteristics.
- The smallest unit of an element is the atom and within this structure we can find even small particles. Two or more atoms make up a molecule.
- The combination of two or more atoms of different elements creates a compound.
- An ion is an atom or compound with either a net positive or negative charge.
- Matter exhibits a number of interesting structural properties. These properties include mass, volume, density, and phase.
- Mass is a measurement of the amount of matter and energy found in an object.
- Volume is the amount of space an object occupies.
- Density relates an object's mass to its volume.
- Matter can exist in three different phases: solid, liquid, and gas. Moving matter from one phase to another is caused by the addition or removal of heat energy.
- Life can synthesize and organize matter into complex organic molecules and structures like cells.
- A cell is the smallest functioning unit of life. Within these units, the processes of metabolism and heredity take place.
- Biologists have defined two basic types of cells: prokaryotes and eukaryotes.
- Some organisms consist of only one cell, but most are multi-cellular. Many multi-cellular organisms can create specialized cells that are arranged into tissues and organs.
- Energy can be defined as the capacity for doing work. It exists in many different forms and can be transferred from one place to another by the processes of conduction, convection, and radiation.
- Some of the more important forms of energy include: heat energy, atomic energy, electromagnetic radiation, and chemical energy.
- We measure energy using units that are based specific definitions. Some of the common measurement units for energy include joules and calories.
- Heat energy is defined as the total kinetic energy found in a body's atoms. Heat should not be confused with temperature, which is a measure of the average kinetic energy of the atoms of a substance.
- Measurements of temperature do not take into account how much heat energy may be stored in a mass of matter.
- We usually measure the temperature or sensible heat of an object or substance with a thermometer. Several different measurement scales have been invented for this instrument. Scientists prefer to use the Kelvin or Celsius scales.
- Specific heat and latent heat are two other heat-related concepts covered in this chapter. Specific heat is the amount of heat energy needed to raise the temperature of one gram of substance one degree Celsius. This quantity varies with the type of matter.
- Latent heat is the energy gained or released when matter undergoes a change in phase. If the phase change is to higher state energy must be added to the substance. Energy is released from a substance when the phase change is to a lower state.
- The laws of thermodynamics describe the behavior of energy flow in natural systems.
- The first law tells us that energy can be transferred from one system to another in a variety of forms. This same law also states that the amount of energy in the Universe is constant and that energy can neither be created nor destroyed.
- The second law suggests that energy flow in natural systems only occurs in one direction. It also suggests that entropy is a by-product of energy use.

- The third law of thermodynamics predicts that absolute zero will occur when all energy and matter are randomly distributed across space.
- Chemical energy comes in many different forms. One very important form is the chemical energy fixed in organic molecules.
- Plants through a process known as photosynthesis initially capture all of the organic chemical energy found in the biosphere. Photosynthesis uses carbon dioxide, water, and sunlight to create glucose, the chemical building block of organic matter.
- Organism, both plant and animal, can release the energy stored in organic matter through cellular respiration. This energy is used to power an organism's metabolism.

IMPORTANT TERMS

Absolute zero
Advection
Amino acid
Asteroid
Atom
Atomic energy
Atomic mass number
Atomic number
Atomic weight
Autotroph
Big Bang
Big Crunch
Calorie (cal)
Carbohydrate
Cell
Cellular respiration
Chemical energy
Chloroplast
Comet
Compound
Conduction
Convection
Cosmic radiation
Density
Deoxyribonucleic acid (DNA)
Dwarf planet
Electrical energy
Electromagnetic radiation
Electron
Element
Energy
Entropy
Eukaryote
Galaxy
Heat capacity
Heat energy
Heterotroph
Inorganic
Ion
Isotope
Joule (J)
Kinetic energy
Latent heat
Light-year
Lipid
Mass
Matter
Milky Way Galaxy
Mitochondria
Molecule
Neutron
Newton (N)
Nuclear fission
Nuclear fusion
Nucleic acid
Nucleus
Organ
Organelle
Organic
Oscillating Universe Theory
Photosynthesis
Planet
Potential energy
Power
Prokaryote
Protein
Proton
Radiation
Radioactive decay
Satellite
Specific heat
Speed of light
Solar system
Star
Temperature
Thermal conductivity
Tissue
Universe
Volume
Watt (W)

CHAPTER REVIEW QUESTIONS

1. Explain the origin, history, and future of the Universe.
2. Describe the various types of celestial bodies that are found in our solar system.
3. What is matter and how is it constructed at the atomic level?
4. Describe the properties of mass, volume, and density as they relate to matter.
5. Describe the difference between inorganic and organic matter. What are the four types of organic matter?
6. What are cells? What is their relationship to life?
7. What is energy? What are some of the various forms of energy?
8. How is energy measured?
9. Define the following energy measurement units: joule, calorie, and watt.
10. Define the following forms of heat energy: specific heat, sensible heat, and latent heat.
11. Outline the three laws of thermodynamics.
12. What are the phases of matter? What is the relationship between energy and phase change?
13. Explain the difference between heat and temperature.
14. Explain how conduction, convection, and radiation move energy on our planet.
15. How are photosynthesis and cellular respiration used by life to create and release chemical energy?

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