CHAPTER 2

CHEMISTRY

Living things are composed of the same materials and are made by the same processes as nonliving things are. These crystals of a substance called urate (LM 90×) are formed in the human kidney.

FOCUS CONCEPT: *Matter, Energy, and Organization*

As you read, become aware of how a basic knowledge of chemistry will help you understand and explain biological processes.

SECTION

2-1

OBJECTIVES

▲ Define *element*, *atom*, *compound*, and *molecule*.

● Draw a model of the structure of an atom.

■ Explain what determines an atom's stability.

◆ Contrast ionic and covalent bonds.

COMPOSITION OF MATTER

Earth supports an enormous variety of organisms. You have learned that all organisms share certain characteristics and life processes. The structure and function of all living things are governed by the laws of chemistry. An understanding of the fundamental principles of chemistry will give you a better understanding of living things and how they function.

MATTER

Everything in the universe is made of matter. **Matter** is anything that occupies space and has mass. **Mass** is the quantity of matter an object has. Mass and weight are not the same; the pull of gravity on an object is what gives an object the property of weight. The same mass would have less weight on the moon than it would on Earth because the moon has less gravitational pull.

Chemical changes in matter are essential to all life processes. Biologists study chemistry because all living things are made of the same kinds of matter that make up nonliving things. By learning how changes in matter occur, you will gain an understanding of the life processes of the organisms you will study.

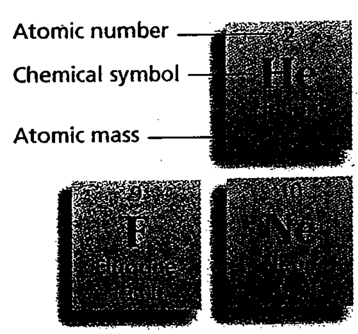
ELEMENTS

Elements are pure substances that cannot be broken down chemically into simpler kinds of matter. More than 100 elements have been identified, though fewer than 30 are important to living things. In fact, more than 90 percent of the mass of all kinds of living things is composed of combinations of just four elements: oxygen, O, carbon, C, hydrogen, H, and nitrogen, N.

Each element has a different chemical symbol. A chemical symbol consists of one or two letters, as shown in Figure 2-1. In most cases, the symbol derives from the first letter or other letters in the name of the element, like C for carbon or Cl for chlorine. The Latin word *natrium* provides the symbol for sodium, Na. The symbol K, for potassium, comes from the Latin word *kalium*.

FIGURE 2-1

All of the elements are arranged on a chart known as the periodic table. Here you see information for three elements from the periodic table. Among the information provided in the periodic table are the atomic number, the chemical symbol, and the atomic mass for each element.



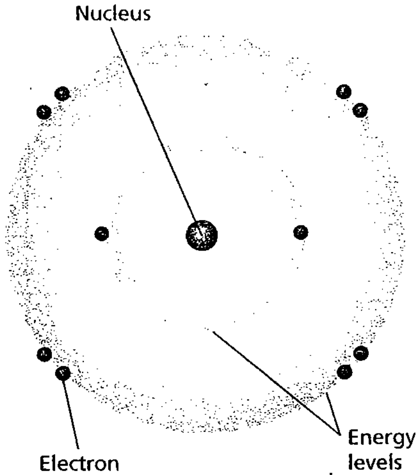


FIGURE 2-2

The electrons in this model of an atom are distributed in two energy levels. The innermost level holds a maximum of two electrons. The second level holds a maximum of eight electrons.

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ATOMS

The simplest particle of an element that retains all of the properties of that element is an **atom.** The properties of different kinds of atoms determine the structure and properties of the matter they compose. Atoms are so small that their true structure cannot be observed. However, scientists have developed models that describe the structure and properties of the atom, as shown in Figure 2-2.

Models of the atom are not meant to show exactly what atoms look like. Rather, they help us understand the structure of atoms and predict how they will act in nature.

The Nucleus

The central core, or **nucleus,** of an atom consists of two kinds of particles. One, the **proton,** has a positive electrical charge. The other, the **neutron,** has no electrical charge. Most of the mass of an atom is concentrated in its nucleus.

All atoms of a given element have the same number of protons. The number of protons in an atom is called the **atomic number** of the element. In the periodic table of elements, the atomic number generally appears directly above the chemical symbol, as shown in Figure 2-1. The atomic number of fluorine is 9, which indicates that each atom of the element fluorine has nine protons.

In an atom, the number of positively charged protons is balanced by an equal number of small, negatively charged particles called **electrons.** The electrical charges of the electrons offset those of the protons, making the net electrical charge of an atom zero.

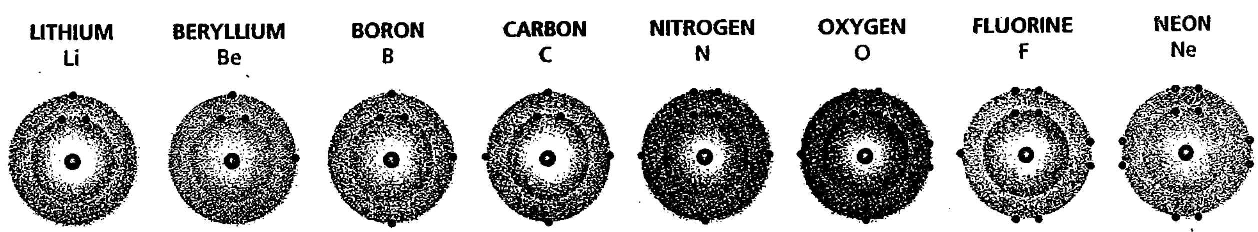
Electrons

Electrons are high-energy particles with very little mass. They move about the nucleus at very high speeds in one of several different **energy levels,** like those shown in Figure 2-2.

Electrons in outer energy levels have more energy than those in inner energy levels. Each energy level can hold only a certain number of electrons. For example, the first energy level, nearest the nucleus, can hold up to two electrons. This is the outermost energy level for the elements hydrogen and helium. The second energy level can hold up to eight electrons. As shown in Figure 2-3, in most elements, the outer energy level is not filled.

FIGURE 2-3

Below are shown some examples of the number of electrons found in the outermost energy level of elements.



COMPOUNDS

Under natural conditions, most elements do not exist by themselves; most elements readily combine with other elements. A pure substance that is made up of atoms of two or more elements is called a **compound.** In a compound, the proportions of each kind of atom are fixed. A chemical formula shows the kind and proportion of atoms of each element that forms a particular compound. For example, the chemical formula for water, H_2O, indicates that the atoms always combine in a proportion of two hydrogen atoms to one oxygen atom.

The physical and chemical properties of a compound differ from the physical and chemical properties of the individual elements that compose it. In nature, the elements oxygen and hydrogen are usually found as gases with the formulas O_2 and H_2. However, when oxygen gas and hydrogen gas combine to form H_2O, the result is a liquid at room temperature. The tendency of elements to combine and form compounds depends on the number and arrangement of electrons in their atoms. An atom is chemically stable when its outermost energy level is filled. Most atoms are not stable in their natural state. Thus, they tend to react, or combine with other atoms, in ways that make the atoms more stable.

Some elements, such as helium and neon, consist of atoms whose energy levels are filled with electrons. As shown in Figure 2-3, the second energy level of neon is its outermost energy level, and it is filled. Thus, neon tends not to react with other elements. By contrast, carbon, nitrogen, and oxygen consist of atoms with unfilled energy levels. Hence, most elements tend to undergo **chemical reactions,** combining in ways that cause their atoms to become stable. In chemical reactions, chemical bonds are broken, atoms are rearranged, and new **chemical bonds,** or attachments, are formed.

Covalent Bonds

A **covalent bond** forms when two atoms share one or more pairs of electrons. Water is made up of one oxygen atom and two hydrogen atoms held together by covalent bonds. Figure 2-4a shows that an atom of hydrogen needs a second electron to achieve stability, giving it two electrons in its outermost energy level. Oxygen needs two more electrons to give it a stable arrangement of eight electrons. Thus, in the presence of one another, hydrogen atoms and oxygen atoms can achieve stability by sharing pairs of electrons in a ratio of two atoms of hydrogen to one atom of oxygen, as shown in Figure 2-4b. The resulting compound, H_2O (water), is essential to the functioning of all living things.

A **molecule** is the simplest part of a substance that retains all of the properties of the substance and that can exist in a free state. For example, each molecule in hydrogen gas consists of two hydrogen atoms bonded to each other. Figure 2-4c shows a model of a water molecule. Some molecules—particularly many of the molecules that biologists study—are large and complex.

Word Roots and Origins

compound

from the Latin *componere,* meaning "to put together"

FIGURE 2-4

Two atoms of hydrogen and one atom of oxygen share electrons in covalent bonds to become stable. Covalent bonding results in the formation of molecules.

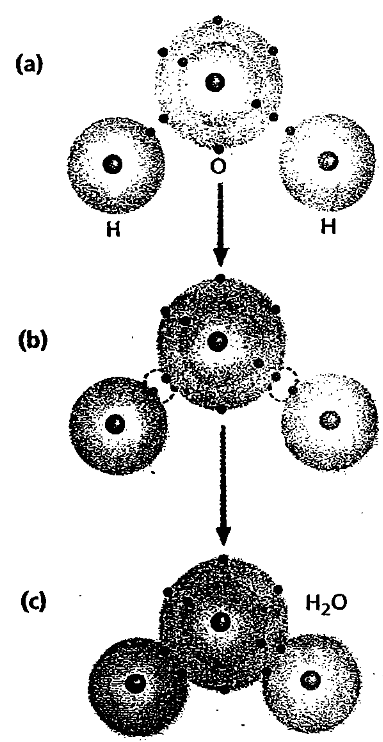
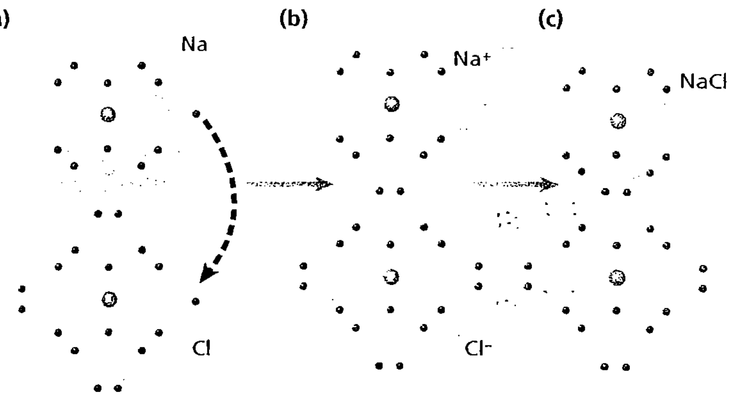


FIGURE 2-5



By losing its outermost electron, a sodium atom becomes an Na^+ ion. By gaining one electron, a chlorine atom becomes a Cl^- ion. Because of their opposite charges, the Na^+ and Cl^- ions are attracted to each other and form an ionic bond.

Ionic Bonds

As shown in Figure 2-5a, both sodium and chlorine atoms have unfilled outermost energy levels and are therefore reactive. Figure 2-5b shows how both atoms achieve stability in the presence of one another. The one outer electron of a sodium atom is transferred to a chlorine atom. This makes the sodium atom more stable than it was—its new outermost energy level is filled with eight electrons. But it also results in a sodium atom with a net positive electrical charge. The sodium atom has 11 protons (11 positive charges) balanced by only 10 electrons (10 negative charges). An atom or molecule with an electrical charge is called an **ion.** The sodium ion is written as Na^+.

As you can see in Figure 2-5b, by gaining an electron from a sodium atom, a chlorine atom has eight electrons in its outermost energy level, making it more stable. But with this additional electron, chlorine becomes a negatively charged ion called chloride, which is abbreviated as Cl^-.

Because positive and negative electrical charges attract each other, the sodium ion and the chloride ion attract each other. This attraction is called an **ionic bond.** The resulting compound, sodium chloride, NaCl, is an ionic compound and is familiar to you as common table salt.

SECTION 2-1 REVIEW

1. Define *element, atom, compound,* and *molecule.*
2. How are particles arranged in the atom?
3. How can we predict which elements are stable under natural conditions and which elements tend to undergo chemical reactions?
4. How does an ionic bond differ from a covalent bond?
5. Neon seldom, if ever, combines with other elements to form compounds. Why is this so?
6. **CRITICAL THINKING** In the early 1900s, hydrogen gas was used to inflate airships. After one large airship crashed and caught on fire, helium gas began to be used to inflate airships. Why was helium preferred over hydrogen?

ENERGY

One important characteristic of all living things is that they use energy. The amount of energy in the universe remains the same over time, but energy can change in form constantly. It is the flow of energy—from the sun to and through almost every organism on Earth—that biologists seek to understand when they study the chemistry of living things.

SECTION

2-2

OBJECTIVES

▲ List the three states of matter, and explain how matter can change state.

● Describe how energy changes are involved in chemical reactions.

■ Explain how enzymes affect chemical reactions in organisms.

◆ Explain what a redox reaction is.

ENERGY AND MATTER

Scientists define **energy** as the ability to do work or cause change. Energy can occur in various forms, and one form of energy can be converted to another form. In a light bulb's filament, electrical energy is converted to radiant energy (light) and thermal energy (heat).

Energy in Living Things

Some forms of energy important to biological systems include chemical energy, thermal energy, electrical energy, and mechanical energy. Biologists often refer to free energy with respect to living systems. **Free energy** is the energy in a system that is available for work. For example, in a cell, it is the energy that is available to fuel cell processes. As energy flows through a single organism, it may be converted from one form to another. For example, if you ate breakfast this morning, your body is at work now changing the chemical energy found in food into thermal and mechanical energy, among other things.

States of Matter

Although it is not apparent when we observe matter, all the atoms and molecules in any substance are in constant motion. The rate at which atoms or molecules of a substance move determines its **state:** solid, liquid, or gas, as shown in Figure 2-6. Particles of a solid are tightly linked together in a definite shape, where they

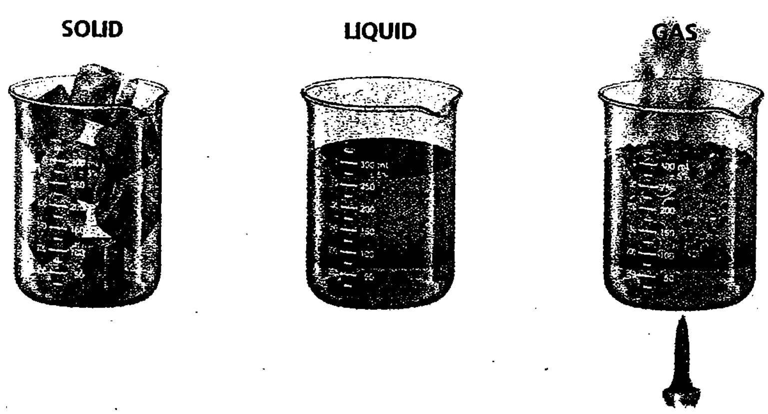
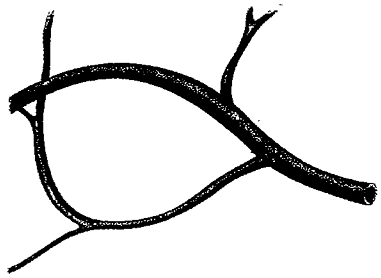


FIGURE 2-6
Matter exists as solids, liquids, and gases. You are familiar with all three states of water.



$CO_2 + H_2O \rightleftharpoons H_2CO_3$

FIGURE 2-7

The reaction illustrated in this figure is reversible. Because the products of the reaction remain in the blood, the reaction can proceed either from left to right or from right to left.

vibrate in place. A solid maintains a fixed volume and shape. Particles of a liquid are not as tightly linked as those in a solid. While a liquid maintains a fixed volume, its particles move more freely than those of a solid, giving a liquid its ability to flow and to conform to the shape of any container. Particles of a gas move the most rapidly. Gas particles have little or no attraction to each other, and they fill the volume of the container they occupy. To cause a substance to change from a solid to a liquid and from a liquid to a gas, thermal energy must be added to the substance.

ENERGY AND CHEMICAL REACTIONS

Living things undergo many thousands of chemical reactions as part of their life processes. Many reactions are very complex and are interrelated, involving a multistep sequence. Other reactions are rather simple. The one described in Figure 2-7 takes place in your blood.

The **reactants** are shown on the left side of the equation. In this reaction, the reactants are CO_2 and H_2O. The **products** of the reaction are shown on the right side. In this reaction, the product is H_2CO_3. Notice that the number of each kind of atom must be the same on either side of the arrow. In a chemical reaction, bonds present in the reactants are broken, the elements are rearranged, and new compounds are formed as the products. The two-direction arrow indicates that this chemical reaction can proceed either way. Carbon dioxide and water can combine to form carbonic acid, H_2CO_3, *or* carbonic acid can break down to carbon dioxide and water.

Energy Transfer

Much of the energy your body needs is provided by sugars from foods. Your body continuously undergoes a series of chemical reactions in which sugar and other substances are broken down to carbon dioxide and water. In this process, energy is released for use by your body. Chemical reactions that involve a net release of free energy are called **exergonic** (EKS-uhr-GAHN-ik) **reactions.** Reactions that involve a net absorption of free energy are called **endergonic** (EN-duhr-GAHN-ik) **reactions.**

Activation Energy

For most chemical reactions—both exergonic and endergonic—to begin, energy must be added to the reactants. In many chemical reactions, the amount of energy needed to start the reaction, called **activation energy,** is high. Figure 2-8 shows the activation energy for a hypothetical chemical reaction.

Certain chemical substances, known as **catalysts** (KAT-uh-LISTS), reduce the amount of activation energy that is needed for a reaction,

Word Roots and Origins

catalyst

from the Greek *katalysis*, meaning "dissolution"

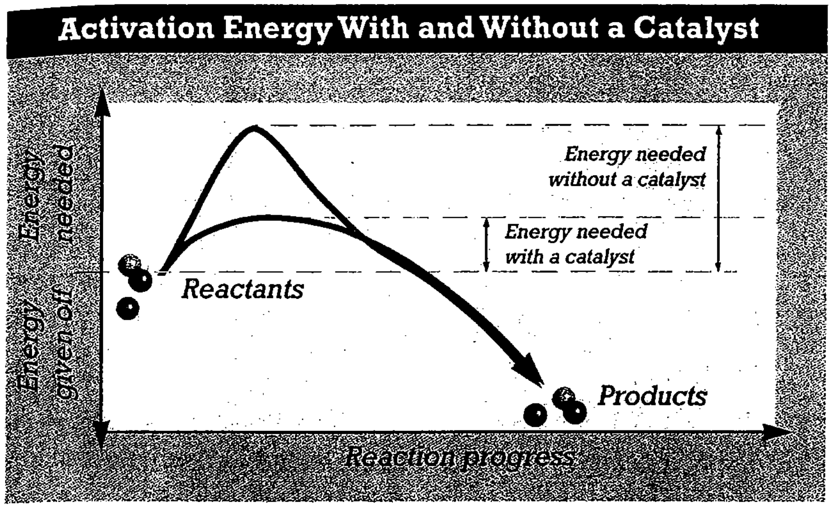


FIGURE 2-8
The blue curve shows the activation energy that must be supplied before this reaction can begin. The activation energy can be reduced, as shown by the pink curve, by adding a catalyst.

as shown in Figure 2-8. A reaction in the presence of the correct catalyst will proceed spontaneously or with the addition of a small amount of energy. **Enzymes** are an important class of catalysts in living things. A single organism may have thousands of different enzymes, each one tailor-made for a different chemical reaction.

Reduction-Oxidation Reactions

You know that there is a constant flow of energy into and throughout living things. Many of the chemical reactions that help transfer *energy* in living things involve the transfer of *electrons*. These reactions in which electrons are transferred between atoms are known as reduction-oxidation reactions, or **redox reactions.** In an **oxidation** (AHKS-uh-DAY-shuhn) **reaction,** a reactant loses one or more electrons, thus becoming more *positive* in charge. For example, remember that a sodium atom loses an electron to achieve stability when it forms an ionic bond, as shown in Figure 2-5. Thus, the sodium atom undergoes oxidation to form an Na^+ ion. In a **reduction reaction,** a reactant gains one or more electrons, thus becoming more *negative* in charge. When a chlorine atom gains an electron to form a Cl^- ion, the atom undergoes reduction. Redox reactions always occur together. An oxidation reaction occurs, and the electron given up by one substance is then accepted by another substance in a reduction reaction.

Quick Lab

Modeling Ionic Bonds

Materials toothpicks, mini marshmallows, peas

Procedure

Use marshmallows to represent chlorine. Use peas to represent sodium. Use toothpicks to create bonds. Make several models of NaCl (sodium chloride).

Analysis Use your models to identify each of the following: a sodium atom, a sodium ion, a chlorine atom, a chloride ion, an ionic bond, and a particle of sodium chloride.

SECTION 2-2 REVIEW

1. What are the three states of matter?
2. How can a substance be changed from a liquid to a gas?
3. State the difference between endergonic and exergonic reactions.
4. Explain how a catalyst affects a reaction.
5. Why does a reduction reaction always accompany an oxidation reaction?
6. **CRITICAL THINKING** Living things need a constant supply of energy, even though many of the chemical reactions they undergo release energy. Why is this true?

Blood Plasma Meets a Need

HISTORICAL PERSPECTIVE

Throughout history, people have understood the importance of blood, seeing it as the river of life that it is. Prior to the 1900s, severe bleeding often resulted in death. But today blood is stored at blood banks, where people "deposit" blood so that they or others can "withdraw" it when needed. Charles Drew was a pioneer in the work of blood transfusions, especially in the use of plasma and the development of blood banks.

The Need

In the early 1930s, Charles Drew, a medical student at McGill University Medical School in Montreal, Quebec, faced a dilemma. Before him lay a man who needed a blood transfusion so that his leg could be amputated. Compatible blood donors could not be found; even the man's sister had a different blood type. So Drew gave his own blood, a perfect match, and the operation proceeded. After that experience, Drew understood more than ever the importance of finding a way to store blood.

Historical Highlights

Before the twentieth century, successful transfusions like Drew's were almost unknown. Of the few attempts made, some succeeded, but most did not. No one was sure why so many transfusions failed.

The early 1900s marked a breakthrough. The Austrian-born American physiologist Karl Landsteiner determined that there are four blood types—A, B, AB, and O—based on the compatibility of markers on the outer surface of red blood cells. Landsteiner's discovery explained why the outcome of transfusions had been so unpredictable. For his work, Landsteiner received the Nobel Prize in medicine or physiology in 1930.

Charles Drew

Determining a person's blood type—called blood typing—became a vital component of transfusions. Blood types that are not compatible form clumps when mixed together. These clumps can block small blood vessels, causing serious complications and often resulting in the death of the patient.

In 1914, sodium citrate was first added to blood to prevent clotting. This made the storage of blood possible for the first time. Refrigerated blood could be stored for five to seven days. (Today whole blood can be safely stored for 21 to 49 days.) Nevertheless, in the early 1930s, blood banks were still uncommon. Most patients received blood directly from a donor.

In 1937, Bernard Fantus, a physician, collected and distributed blood for transfusions, establishing the first nonprofit blood bank at Cook County Hospital in Chicago. It was Fantus who coined the term *blood bank*. Charles Drew, however, was the one who recognized that a liquid solution in blood called *plasma* could help solve problems associated with storage, making transfusions available on a large scale.

The Composition of Blood

In 1938, Drew and physician John Scudder studied blood chemistry and transfusion, with a focus toward finding a safe way to preserve blood. Blood has two main components: cells and plasma. Three types of cells—red blood cells, white blood cells, and platelets—make up about 45 percent of blood. The other approximately 55 percent of blood is made up of plasma, an amber-colored solution containing more than 100 different solutes, including nutrients, antibodies, hormones, and proteins. Almost 90 percent of plasma is water.

Although plasma contains antibodies that may cause clumping when mixed with incompatible blood types, in most cases transfused plasma dilutes rapidly in the patient's blood, minimizing the risk of clumping. Because red blood cells carry the markers that determine ABO blood types, by removing the red blood cells from blood, the remaining plasma can usually be used safely without type testing. In addition, plasma can be dehydrated and easily stored.

Through his research, Drew concluded that although plasma lacks important components of whole blood, it might be a viable substitute for blood in emergency situations. For example, plasma could save lives on the battlefield.

Charles R. Drew, far left, appears in 1940 with the first mobile blood-collection unit.

Response to Wartime Needs

In 1940, Germany's attack on France created a need for a huge blood supply. As experts in transfusion met to decide how to respond, Drew presented his findings on plasma. Although his research was incomplete, the United States began to provide liquid plasma and whole blood for France. However, before any deliveries could be made, France fell to the German army. Soon the "Blood for Britain" program was under way, with Drew as its medical supervisor.

Drew coordinated the American effort. Working with the National Research Council and the American Red Cross, he set up collection centers and was in charge of coordinating the medical aspects of the program, including the establishment of uniform records, standard equipment, and criteria to ensure the safety of the final product. Americans gave blood generously. Drew wanted the blood banks to be well stocked when the United States entered the war—as it soon did.

The nation's blood supply was ready. Stored blood and plasma has subsequently saved thousands of lives—in both wartime and peacetime. Today blood banks are found in medical facilities worldwide.

Transfusion Update

Early in the 1980s, the practice of blood transfusion had to be reexamined. Some transfused blood was found to carry HIV, causing AIDS in a number of people. Hemophiliacs, whose blood does not clot, were especially vulnerable. It is estimated that half of the hemophiliacs in the United States contracted HIV before adequate testing of donated blood began.

Since 1985, careful screening for HIV, hepatitis, and other diseases has almost entirely removed the risk of receiving contaminated blood. Even so, the level of fear remains high, accounting for a sharp decline in the amount of blood donated. Many people now bank their own blood for later use in surgery. Blood can also be collected during surgery and returned to the patient later.

The AIDS epidemic has triggered a race to create artificial blood. However, blood chemistry is extremely complex, and the process has proven more difficult than expected. Several companies have begun testing potential artificial-blood products. Some of these substitutes make use of chemically treated animal blood and outdated human blood. As a new century begins, the use of artificial blood may be, as one headline put it, "a heartbeat away."

Bags of blood ready for transfusion are kept in cold storage.

SECTION

2-3

OBJECTIVES

▲

Define *solution, solute, solvent,* and *concentration.*

●

Explain the dissociation of water.

■

Contrast properties of acids and bases.

◆

Describe the use of the pH scale.

◆

Explain the action of buffers.

Word Roots and Origins

solvent

from the Latin *solvere,* meaning "to loosen"

SOLUTIONS

The chemistry of living things involves the study of solutions. A large proportion of the mass of living things is water, and the chemical reactions of life occur for the most part in water solutions. The electricity that courses through your nerves is transmitted through watery pathways of dissolved ions. Chemical messengers that regulate your body's metabolism move through the watery medium of your blood.

DESCRIBING SOLUTIONS

A **solution** is a mixture in which one or more substances are uniformly distributed in another substance. Solutions can be mixtures of liquids, solids, or gases. For example, plasma, the liquid part of blood, is a very complex solution. It is composed of many types of ions and large molecules, as well as gases, that are dissolved in water. The **solute** (SAHL-YOOT) is the substance dissolved in the solution. The particles that compose a solute may be ions, atoms, or molecules. The **solvent** is the substance in which the solute is dissolved. For example, when sugar, a solute, and water, a solvent, are mixed, a solution of sugar water results. Though the sugar dissolves in the water, neither the sugar molecules nor the water molecules are altered chemically. If the water is boiled away, the sugar molecules remain and are unchanged.

Solutions can be composed of various proportions of a given solute in a given solvent. Thus, solutions can vary in concentration. The **concentration** of a solution is the measurement of the amount of solute dissolved in a fixed amount of the solution. For example, a 2 percent saltwater solution contains 2 g of salt dissolved in enough water to make 100 mL of solution. The more solute dissolved, the greater the concentration of the solution. A **saturated solution** is one in which no more solute can dissolve.

Aqueous (AY-kwee-uhs) **solutions**—solutions in which water is the solvent—are universally important to living things. You should be able to think of many different aqueous solutions important to living things. Marine microorganisms spend their lives immersed in the sea, an aqueous solution. Most nutrients that plants need are in aqueous solutions in moist soil. Body cells exist in an aqueous solution of intercellular fluid and are themselves filled with fluid.

ACIDS AND BASES

One of the most important aspects of a living system is the degree of its acidity or alkalinity. What do we mean when we say *acid* and *alkaline*?

Dissociation of Water

In water, the force of attraction between molecules is so strong that the oxygen atom of one water molecule can actually remove the hydrogen atom from the other water molecule. This breaking apart of the water molecule into two ions of opposite charge is called **dissociation** and is shown by the chemical equation below.

$$H_2O \rightleftharpoons H^+ + OH^-$$

One water molecule, H_2O, dissociates to form two ions, H^+ and OH^-. The OH^- ion is known as the **hydroxide ion.** The free H^+ ion can react with another water molecule, as shown in the following equation.

$$H^+ + H_2O \rightleftharpoons H_3O^+$$

The H_3O^+ ion is known as the **hydronium ion.** Acidity or alkalinity is a measure of the relative amounts of hydronium ions and hydroxide ions dissolved in a solution. If the number of hydronium ions in a solution equals the number of hydroxide ions, the solution is said to be neutral. Pure water contains equal numbers of hydronium ions and hydroxide ions and is therefore a neutral solution.

Acids

If the number of hydronium ions in a solution is greater than the number of hydroxide ions, the solution is an **acid.** Consider what happens when hydrogen chloride, HCl, a gas, is dissolved in water. Some of its molecules dissociate to form hydrogen ions, H^+, and chloride ions, Cl^-.

$$HCl \rightleftharpoons H^+ + Cl^-$$

These free hydrogen ions combine with water molecules to form hydronium ions, H_3O^+. This aqueous solution contains many more hydronium ions than it does hydroxide ions, making it an acidic solution. Acids tend to have a sour taste. In concentrated forms, they are highly corrosive to some materials, as you can see in Figure 2-9.

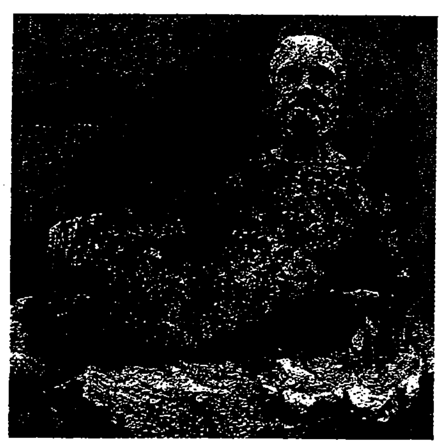


FIGURE 2-9

Acids can have a significant impact on our environment. Sulfur dioxide, SO_2, which is produced when fossil fuels are burned, reacts with water in the atmosphere to produce acid precipitation. Acid precipitation can make lakes and rivers too acidic to support life and can even corrode stone, such as this marble carving.

Eco Connection

Acid Precipitation

Acid precipitation, more commonly called *acid rain,* describes rain, snow, sleet, or fog that contains high levels of sulfuric and nitric acids. These acids form when sulfur dioxide gas, SO_2, and nitrogen oxide gas, NO, react with water in the atmosphere to produce sulfuric acid, H_2SO_4, and nitric acid, HNO_3.

Acid precipitation makes soil and bodies of water, such as lakes, more acidic than normal. These high acid levels can harm plant and animal life directly. A high level of acid in a lake may kill mollusks, fish, and amphibians. Even in a lake that does not have a very elevated level of acid, acid precipitation may leach aluminum and magnesium from soils, poisoning water-dwelling species.

Reducing fossil-fuel consumption, such as occurs in gasoline engines and coal-burning power plants, should reduce high acid levels in precipitation. You can help by learning about alternative fuel sources and legislation proposed to encourage or mandate use of non-fossil-fuel sources of energy.

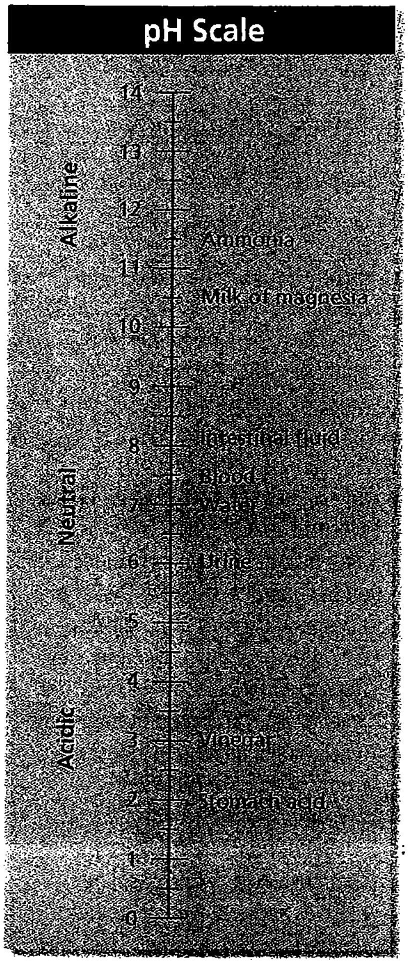


FIGURE 2-10

Some of your body fluids are acidic, while others are alkaline. A solution with a pH above 7 is alkaline, while a solution with a pH below 7 is acidic. Each unit on the pH scale reflects a tenfold change in acidity or alkalinity.

Bases

If sodium hydroxide, NaOH, a solid, is dissolved in water, some of it dissociates to form sodium ions, Na^+, and hydroxide ions, OH^-, as shown in the equation below.

$$NaOH \rightleftharpoons Na^+ + OH^-$$

This solution then contains more hydroxide ions than hydronium ions and is therefore defined as a **base.** The adjective ***alkaline*** refers to bases. Bases have a bitter taste. They tend to feel slippery because the OH^- ions react with the oil on our skin to form a soap. In fact, commercial soap is made by reacting a base with a fat.

pH

Scientists have developed a scale for comparing the relative concentrations of hydronium ions and hydroxide ions in a solution. It is called the **pH scale,** and it ranges from 0 to 14, as shown in Figure 2-10. A solution with a pH of 0 is very acidic, a solution with a pH of 7 is neutral, and a solution with a pH of 14 is very basic. A solution's pH is measured on a logarithmic scale. That is, the change of one pH unit reflects a tenfold change in the acidity or alkalinity. For example, a solution with a pH of 4 has 10 times more H_3O^+ ions than a solution with a pH of 5 and 100 times more H_3O^+ ions than a solution with a pH of 6. The pH of a solution can be measured with litmus paper or with some other chemical indicator that changes color at various pH levels.

Buffers

The control of pH is important for living systems. Enzymes such as those you read about in Section 2-2 can function only within a very narrow pH range. The control of pH in organisms is often accomplished with buffers. **Buffers** are chemical substances that neutralize small amounts of either an acid or a base added to a solution. As Figure 2-10 shows, the composition of your internal environment—in terms of acidity and alkalinity—varies greatly. Some of your body fluids, such as stomach acid and urine, are acidic. Others, such as intestinal fluid and blood, are basic or alkaline. Complex buffering systems maintain the pH values of your body's many fluids at normal and safe levels.

SECTION 2-3 REVIEW

1. What is a solution?
2. Describe the dissociation of water.
3. What pH value is neutral?
4. Define *acid* and *base*.
5. What is a buffer?
6. **CRITICAL THINKING** The active ingredient in aspirin is acetylsalicylic acid. Why would doctors recommend buffered aspirin for some people, especially those who have a "sensitive" stomach?

CHAPTER 2 REVIEW

SUMMARY/VOCABULARY

2-1

- Elements are substances that cannot be broken down by chemical means into simpler substances.
- Atoms are composed of protons, neutrons, and electrons. Protons and neutrons compose the nucleus of the atom. Electrons travel around the nucleus.
- Compounds consist of atoms of two or more elements that are joined by chemical bonds in a fixed proportion.
- Most elements react to form chemical bonds so that their atoms become stable. Atoms achieve stability when their outermost energy level is filled.
- A chemical reaction is the process of breaking chemical bonds, rearranging the atoms, and forming new bonds.
- A covalent bond is formed when two atoms share electrons.
- A molecule consists of two or more atoms held together by covalent bonds.
- An ionic bond is formed when one atom gives up an electron to another. The positive ion is then attracted to a negative ion to form the ionic bond.

Vocabulary

atom (32)	covalent bond (33)	ionic bond (34)	nucleus (32)
atomic number (32)	electron (32)	mass (31)	proton (32)
bond (33)	element (31)	matter (31)	
chemical reaction (33)	energy level (32)	molecule (33)	
compound (33)	ion (34)	neutron (32)	

2-2

- Addition of thermal energy to a substance can cause its state to change from a solid to a liquid and from a liquid to a gas.
- Chemical reactions that involve a net release of energy are called exergonic reactions. Chemical reactions that involve a net absorption of energy are called endergonic reactions.
- The activation energy is the amount of energy required for a chemical reaction to begin.
- Catalysts lower the amount of activation energy necessary for a reaction to begin.
- A chemical reaction in which electrons are exchanged between atoms is called a reduction-oxidation, or redox, reaction.

Vocabulary

activation energy (36)	enzyme (37)	product (36)	state (35)
catalyst (36)	exergonic reaction (36)	reactant (36)	
endergonic reaction (36)	free energy (35)	redox reaction (37)	
energy (35)	oxidation reaction (37)	reduction reaction (37)	

2-3

- A solution consists of a solute dissolved in a solvent, which is often water. A solution with water as the solvent is known as an aqueous solution.
- An acidic solution contains more hydronium ions than it does hydroxide ions. A basic or alkaline solution contains more hydroxide ions than it does hydronium ions.
- The pH scale indicates the relative concentration of hydronium ions and hydroxide ions in solution. The pH scale ranges from 0 to 14, with 0 being the most acidic, 7 being neutral, and 14 being the most alkaline.
- Buffers are chemicals that neutralize the effects of adding small amounts of either an acid or a base to a solution.

Vocabulary

acid (41)	buffer (42)	hydroxide ion (41)	solution (40)
alkaline (42)	concentration (40)	pH scale (42)	solvent (40)
aqueous solution (40)	dissociation (41)	saturated solution (40)	
base (42)	hydronium ion (41)	solute (40)	

REVIEW

Vocabulary

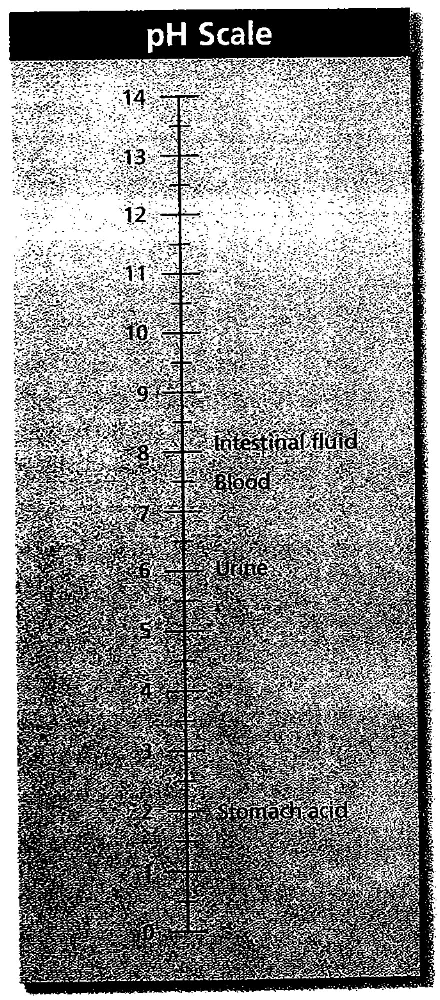
1. Explain the relationship between electrons, neutrons, and protons.
2. What is the difference between an element and a compound?
3. Distinguish the differences in composition between an acid and a base.
4. Identify the type of reaction that releases free energy.
5. How are the processes of oxidation and reduction related?

Multiple Choice

6. The nucleus of an atom is made up of (a) protons and neutrons (b) protons and electrons (c) elements and compounds (d) negatively charged particles.
7. High-energy particles that circle the nucleus of an atom are (a) ions (b) protons (c) electrons (d) neutrons.
8. The way in which elements bond to form compounds depends on the (a) structural formula of the compound (b) dissociation of the ions in the compound (c) number and arrangement of electrons in the atoms of the elements (d) model of the atom.
9. If an atom is made up of 6 protons, 7 neutrons, and 6 electrons, then its atomic number is (a) 19 (b) 13 (c) 7 (d) 6.
10. Atoms in a solid (a) are fixed in space and show no movement (b) are fixed in space but vibrate in place (c) move rapidly through space (d) repel each other.
11. The amount of energy required for a chemical reaction to begin is called (a) chemical energy (b) mechanical energy (c) electrical energy (d) activation energy.
12. The process in which a chemical reactant loses an electron, becoming more positively charged, is called (a) oxidation (b) reduction (c) metabolism (d) stabilization.
13. In a reduction reaction, an atom gains a(n) (a) proton (b) neutron (c) electron (d) nucleus.
14. An aqueous solution that contains more hydroxide ions than hydronium ions is a(n) (a) acid (b) base (c) gas (d) solid.
15. Acid formed from sulfur dioxide in the atmosphere is present in (a) rocks (b) acid precipitation (c) weak bases (d) pure water.

Short Answer

16. Use the pH scale shown below to answer the following questions:
    a. What is the most acidic body fluid represented?
    b. What is the most alkaline body fluid represented?
    c. What body fluid is closest to being a neutral solution?
    d. Which body fluid is most extremely acidic or basic; that is, which body fluid deviates the most from neutral pH?



17. An oxygen atom has six electrons in its outermost energy level. Explain why two oxygen atoms must share four electrons when they form a covalent bond.
18. What is an ion?
19. How are electrons distributed in a covalent bond?
20. Name the physical states that matter can exist in.
21. In a chemical equation, what does a two-direction arrow mean?
22. Many reactions in the cell are exergonic. Why, then, do cells need a continuous supply of energy?
23. What happens when water dissociates?
24. What does the word *alkaline* mean?
25. What does a buffer do?

CRITICAL THINKING

1. Hydrogen gas exists as H_2 rather than H. Why is this so?
2. How can a substance be changed from a solid to a liquid? from a liquid to a gas?
3. A magnesium atom has two electrons in its outermost energy level. A sulfur atom has six electrons in its outermost level. How will the two atoms react to form a bond? Explain why this is considered a redox reaction.
4. A dam located on a fast-flowing mountain stream generates electricity. What kind of energy is transformed to create electricity?
5. The table shows melting and boiling points at normal pressure for five different elements or compounds. Above the boiling point, a compound or element exists as a gas. Below the freezing point, a compound or element exists as a solid. Use the table to answer the following questions:
   a. Under normal temperature and pressure conditions, which substances exist as solids? as liquids? as gases?
   b. Which substance exists as a liquid over the broadest range of temperature?
   c. Which substance exists as a liquid over the narrowest range of temperature?
   d. Which one of the substances are you least likely to encounter as a gas?

Melting and Boiling Points at Normal Pressure

Substance	Melting point (°C)	Boiling point (°C)
Aluminum	658	2330
Argon	−190	−186
Chlorine	−104	−34
Mercury	−39	357
Water	0	100

EXTENSION

1. Read "The Femtosecond Camera Shutter" in *Scientific American*, January 2000, on page 15, and answer the following questions: What is the main obstacle scientists encounter in observing chemical reactions step by step? What was the key process Dr. Zewail used to observe chemical reactions? What was the chemical reaction observed using this new technique? What goals may ultimately be achieved using this technique?
2. Dissolve table salt or sugar by stirring it into water at room temperature until it is saturated. (The solution is saturated when excess salt or sugar stays at the bottom of the container.) Remove the clear solution at the top with a spoon, and place the remaining saturated solution in the refrigerator. After two hours, observe the cooled solution. What do your observations tell you about the effect of temperature on molecules in solution?