FIGURE 1-15

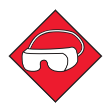
Good laboratory practice involves protecting yourself and others by being safe.

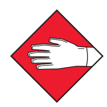
SAFETY

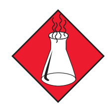
Studying living things is interesting, fun, and rewarding, but it can be hazardous. The hazards can be chemical, physical, radiological, or biological and can vary between the the lab and the field. For example, getting splashed in the eye with a blinding chemical is more likely to occur in the laboratory, but falling down a cliff or getting bitten by a poisonous spider is more likely to occur in the field.

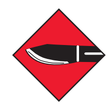
Good Laboratory Practice

Lab safety involves good laboratory practice, which means establishing safe, common-sense habits, as shown in Figure 1-15. Never work alone in the lab or without proper supervision by the teacher, and always ask your teacher before using any equipment. The diagram below shows the safety symbols used in this book. More information on lab safety and the safety symbols can be found in the Appendix.


Eye Safety


Hand Safety


Safety with Gases


Sharp-Object Safety


Clothing Protection

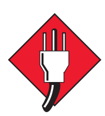

Animal Care and Safety


Heating Safety


Hygienic Care


Glassware Safety


Proper Waste Disposal


Electrical Safety


Plant Safety


Chemical Safety

SECTION 4 REVIEW

1. List the four major parts of a compound light microscope.
2. What is the difference between the magnification and resolution of an image under a microscope?
3. Compare the function of a transmission electron microscope with that of a scanning electron microscope.
4. What is the importance of scientists using a common SI system of measurement?
5. How would you convert kilometers to millimeters?
6. Name the safety symbols used in this textbook.

CRITICAL THINKING

7. **Applying Information** A biologist thinks a virus, which is much smaller than a cell, is likely to cause a disease. Which type of microscope is most likely to be used to view the internal structure of a virus?
8. **Calculating Information** How would you convert cubic meters to cubic centimeters?
9. **Calculating Information** On a light microscope, an objective lens magnifies the view of some pond water 25 times, and the ocular lens magnifies it 10 times further. What is the final magnification of the image?

CHAPTER HIGHLIGHTS

SECTION 1 The World of Biology

- Biology is the study of life and can be used to both solve societal problems and explain aspects of our daily lives.
- Living things share the same 7 characteristics: organization and cells, response to stimuli, homeostasis, metabolism, growth and development, reproduction, and evolution.
- Multicellular organisms show a hierarchy of organization going from the organism to the atom.
- To stay alive, living things must maintain homeostasis, obtain and use energy, and pass on hereditary information from parents to offspring, also called reproduction.

Vocabulary

biology (p. 5)	**multicellular** (p. 7)	**biological molecule** (p. 7)	**development** (p. 8)
organization (p. 6)	**organ** (p. 7)	**homeostasis** (p. 8)	**reproduction** (p. 9)
cell (p. 7)	**tissue** (p. 7)	**metabolism** (p. 8)	**gene** (p. 9)
unicellular (p. 7)	**organelle** (p. 7)	**cell division** (p. 8)	

SECTION 2 Themes in Biology

- Three themes in biology are the unity of life's diversity, the interdependence of organisms, and evolution of life.
- Living organisms show diversity and can be classified into domains and kingdoms.
- Organisms live in interdependent communities and interact with both organisms and the environment.
- Evolution helps to explain how species came to exist, have changed over time, and adapt to their environment.

Vocabulary

domain (p. 11)	**ecology** (p. 11)	**evolution** (p. 12)	**adaptation** (p. 12)
kingdom (p. 11)	**ecosystem** (p. 11)	**natural selection** (p. 12)	

SECTION 3 The Study of Biology

- The scientific method involves making observations, asking questions, forming hypotheses, designing experiments, analyzing data, and drawing conclusions.
- Trying to answer questions about observations helps scientists form hypotheses.
- A controlled experiment has a control and experimental group, and tests independent and dependent variables.
- Scientists analyze data to draw conclusions about the experiment performed.
- A theory is a set of related hypotheses confirmed to be true many times.
- Communication between scientists about their methods and results helps prevent dishonesty and bias in science.

Vocabulary

scientific method (p. 13)	**prediction** (p. 13)	**experimental group** (p. 15)	**dependent variable** (p. 16)
observation (p. 13)	**experiment** (p. 13)	**independent variable** (p. 15)	**theory** (p. 17)
hypothesis (p. 13)	**control group** (p. 15)		**peer review** (p. 19)

SECTION 4 Tools and Techniques

- Four major parts of a compound light microscope are the ocular lens, objective lens, stage, and light source.
- Transmission and scanning electron microscopes provide greater magnification than light microscopes.
- Scientists use the metric system to take scientific measurements.
- Lab safety is a good laboratory practice.

Vocabulary

compound light microscope (p. 21)	**objective lens** (p. 21)	**nosepiece** (p. 22)	**transmission electron microscope (TEM)** (p. 22)
eyepiece (ocular lens) (p. 21)	**stage** (p. 21)	**resolution** (p. 22)	**metric system** (p. 23)
	light source (p. 21)	**scanning electron microscope (SEM)** (p. 22)	**base unit** (p .23)
	magnification (p. 22)		

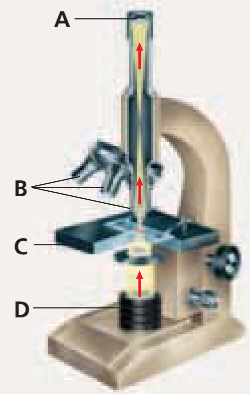
CHAPTER REVIEW

Using Vocabulary

1. For each pair of terms, explain how the meanings of the terms differ.
   a. *unicellular* and *multicellular*
   b. *homeostasis* and *metabolism*
   c. *natural selection* and *adaptation*
   d. *hypothesis* and *theory*
   e. *magnification* and *resolution*
2. Explain the relationship between an independent variable and a dependent variable.
3. Use the following terms in the same sentence: *observation, hypothesis, prediction,* and *experiment.*
4. **Word Roots and Origins** The word *magnification* is derived from the Latin *magnificus* or *magnus,* which means "large" or "great." Using this information, explain why the term *magnification* is a good name for the function it describes.

Understanding Key Concepts

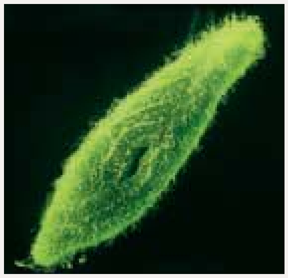
5. **Describe** why learning about biology is relevant to a person's life.
6. **Describe** one way in which biology affects our society.
7. **Summarize** the characteristics of living things.
8. **List** the hierarchy of organization in a snowy owl.
9. **Explain** how homeostasis and metabolism are interrelated.
10. **Compare** the processes of growth, development, and reproduction.
11. **State** three major themes found in biology.
12. **Identify** how the "tree of life" can help explain both the unity and diversity of life.
13. **Describe** the interdependence of living organisms.
14. **Summarize** how evolution helps explain the diversity of life.
15. **Sequence** the main steps of the scientific method.
16. **Explain** how observations are used to form hypotheses.
17. **Summarize** how biologists set up controlled experiments.
18. **State** the purpose of analyzing data that are collected during an experiment.
19. **Summarize** how a hypothesis becomes a theory.
20. **Describe** two types of scientific models.
21. **Identify** how a peer review keeps scientists honest.
22. **Name** the part of the compound light microscope denoted by each letter in the figure below.



23. **Differentiate** between the scanning electron microscope and the transmission electron microscope.
24. **Describe** the relationship between a kilometer, meter, and micrometer.
25. **Explain** why scientists throughout the world use the SI system.
26. **List** three safety symbols used in this textbook.
27. **CONCEPT MAPPING** Use the following terms to create a concept map that outlines the steps of the scientific method: *observations, experiments, conclusions, questions, hypotheses, data analyses, predictions, theories,* and *communication.*

Critical Thinking

28. **Forming Hypotheses** Go to a window or outside, and observe a bird's behavior for a few minutes. Record your observations, and write down one question about bird behavior and one hypothesis that answers the question.
29. **Analyzing Concepts** One of the most important parts of any scientific publication is the part called Methods and Materials, in which the scientist describes the procedure used in the experiment. Why do you think such details are so important?
30. **Making Calculations** Determine the number of liters that are in 150 kiloliters.
31. **Making Comparisons** Look at the photographs below. The TEM (left) is a photo of a paramecium. The SEM (right) is also a photo of a paramecium. Compare and contrast what each electron micrograph reveals to you about this organism.



Standardized Test Preparation

DIRECTIONS: Choose the letter of the answer choice that best answers the question.

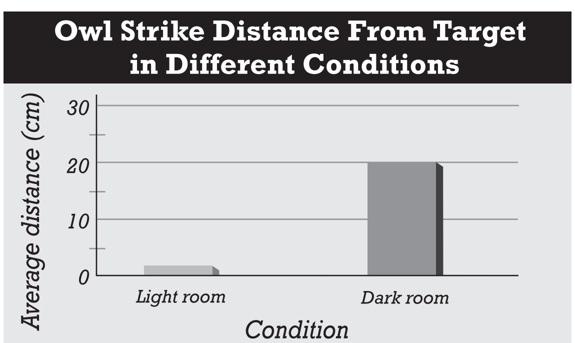
1. Which of the following does evolution help explain?
A. how organisms reproduce
B. how organisms grow and develop
C. how organisms are related to each other
D. how organisms obtain and metabolize energy

2. Which of the following is the hereditary material in most living things?
F. DNA
G. lipids
H. oxygen
J. carbon dioxide

3. Which of the following does the hierarchy of organization within an organism describe?
A. metabolism
B. homeostasis
C. internal structures
D. relationship to the physical environment

4. To which of the following does the resolution of a microscope refer?
F. its ability to show detail clearly
G. its power to scan the surface of an object
H. its series of interchangeable objective lenses
J. its power to increase an object's apparent size

INTERPRETING GRAPHICS: The graph below shows the distance it takes an owl to strike a mouse under different conditions. Use the graph to answer the question that follows.

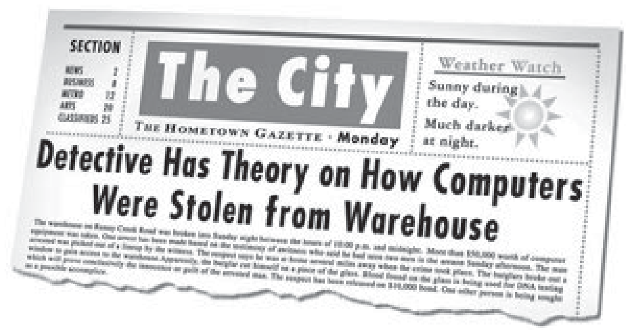


5. Which of the following is the dependent variable in the experiment?
A. twilight
B. complete darkness
C. daylight
D. distance from target

DIRECTIONS: Complete the following analogy.

6. compound light microscope : light :: TEM:
F. tissues
G. electrons
H. organelles
J. organ systems

INTERPRETING GRAPHICS: The figure below shows a newspaper clipping. Use the figure to answer the question that follows.



SECTION

The City

THE HOMETOWN GAZETTE • Monday

Weather Watch

Sunny during the day. Much darker at night.

Detective Has Theory on How Computers Were Stolen from Warehouse

7. Which of the following terms most accurately reflects the use of the term theory in the newspaper headline above?
A. law
B. fact
C. hypothesis
D. experiment

SHORT RESPONSE

Dolly was cloned from mammary cells from an adult female sheep. She was an exact genetic copy of her mother.

Explain whether Dolly represents a product of sexual reproduction or asexual reproduction.

EXTENDED RESPONSE

Life is so diverse, yet it is characterized by a unity. The tree of life can relate life's unity and diversity.

Part A Describe the relationship between animals, plants, fungi, protists, bacteria, and archaea in the "tree of life."

Part B Explain how the "tree of life" represents and relates both the unity and diversity of life.

Test TIP When faced with similar answers, define the answer choices and then use that definition to narrow down the choices on a multiple-choice question.

Using SI Units

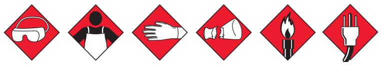
OBJECTIVES

- Express measurements in SI units.
- Read a thermometer.
- Measure liquid volume using a graduated cylinder.
- Measure mass using a balance.
- Determine the density (mass-to-volume ratio) of two different liquids.

MATERIALS

- safety goggles
- lab apron
- protective gloves
- 75 mL light-colored sand
- 75 mL dark-colored sand
- 1 100 mL graduated cylinder
- Celsius thermometers, alcohol filled (2)
- 5 oz plastic cups (4)
- graph paper
- heat-protective gloves
- light source
- stopwatch or clock
- ring stand or lamp support
- 25 mL corn oil
- 25 mL water
- clear-plastic cup
- balance

SAFETY



Background

1. What does the abbreviation *SI* stand for?
2. List the seven SI base units.

PART A Measuring Temperature

1. In your lab report, prepare a data table similar to Table A, above right.
2. Using a graduated cylinder, measure 75 mL of light-colored sand and pour it into one of the small plastic cups. Repeat this procedure with the dark-colored sand and another plastic cup.

TABLE A ***SAND TEMPERATURE***

	Temperature (°C)	
Time (min)	**Dark-colored sand**	**Light-colored sand**
Start		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

3. Level the sand by placing the cup on your desk and sliding the cup back and forth.
4. Insert one thermometer into each cup. The zero line on the thermometer should be level with the sand, as shown in the figure below. Re-level the sand if necessary.

5. **CAUTION** **Wear heat-protective gloves when handling the lamp. The lamp will become very hot and may burn you.** Using a ring stand or lamp support, position the lamp approximately 9 cm from the top of the sand, as shown in the figure on p. 28. Make sure the lamp is evenly positioned between the two cups.
6. Before turning on the lamp, record the initial temperature of each cup of sand in your data table.
7. Note the time or start the stopwatch when you turn on the lamp. The lamp will become hot and warm the sand. Check the temperature of the sand in each container at one-minute intervals for 10 minutes. Record the temperature of the sand after each minute in your data table.

PART B Comparing the Density of Oil and Water

8. In your lab report, prepare a data table similar to Table B below.

TABLE B *DENSITY OF TWO LIQUIDS*

a. Mass of empty oil cup	______	**g**
b. Mass of empty water cup	______	**g**
c. Mass of cup and oil	______	**g**
d. Mass of cup and water	______	**g**
e. Volume of oil		**25 mL**
f. Volume of water		**25 mL**
Calculating Actual Mass		
Oil Item c − Item a =	______	**g**
Water Item d − Item b =	______	**g**
g. Density of oil	______	**g/ml**
h. Density of water	______	**g/ml**

9. Label one clean plastic cup "oil," and label another "water." Using a balance, measure the mass of each plastic cup, and record the value in your data table.
10. Using a clean graduated cylinder, measure 25 mL of corn oil and pour it into the plastic cup labeled "oil." Using a balance, measure the mass of the plastic cup containing the corn oil, and record the mass in your data table.
11. Using a clean graduated cylinder, measure 25 mL of water and pour it into the plastic cup labeled "water." Using a balance, measure the mass of the plastic cup containing the water, and record the mass in your data table.
12. To find the mass of the oil, subtract the mass of the empty cup from the mass of the cup and the oil together.
13. To find the density of the oil, divide the mass of the oil by the volume of the oil, as shown in the equation below:

$$\text{Density of oil} = \frac{\text{mass of oil}}{\text{volume of oil}} = \underline{\qquad\qquad} \text{ g/mL}$$

14. To find the mass of water, subtract the mass of the empty cup from the mass of the cup and the water together.
15. To find the density of the water, divide the mass of the water by the volume of the water, as shown in the equation below:

$$\text{Density of water} = \frac{\text{mass of water}}{\text{volume of water}} = \underline{\qquad\qquad} \text{ g/mL}$$

16. Combine the oil and water in the clear cup, and record your observations in your lab report.
17. Clean up your materials, and wash your hands before leaving the lab.

Analysis and Conclusions

1. Graph the data you collected in Part A. Plot time on the *x*-axis and temperature on the *y*-axis.
2. Based on your data from Part A, what is the relationship between color and heat absorption?
3. How might the color of the clothes you wear affect how warm you are on a sunny 90° day?
4. In Part B, what did you observe when you combined the oil and water in the clear cup? Relate your observation to the densities that you calculated.
5. What could you infer about the value for the density of ice if you observe it to float in water?
6. How would your calculated values for density be affected if you misread the volume measurement on the graduated cylinder?

Further Inquiry

Pumice is a volcanic rock that has a density less than 1.00 g/cm^3. How would you prove this if you did not have a balance to weigh the pumice? (Hint: The density of water is 1.00 g/cm^3.)

CHAPTER 2

CHEMISTRY OF LIFE

All living things are made of the same basic materials: carbon, hydrogen, oxygen, and nitrogen. Living things, such as this jellyfish, *Pseudorhiza haeckeli,* are made of cells that are composed primarily of water. The chemical reactions of life occur in the aqueous environment of the cell.

SECTION 1 ***Composition of Matter***

SECTION 2 ***Energy***

SECTION 3 ***Water and Solutions***

Biology Virtual Investigations
The Macromolecules of Life

COMPOSITION OF MATTER

Earth supports an enormous variety of organisms. The structure and function of all living things are governed by the laws of chemistry. An understanding of the basic principles of chemistry will give you a better understanding of living things and how they function.

SECTION 1

OBJECTIVES

- **Define** the term *matter.*
- **Explain** the relationship between elements and atoms.
- **Draw** and label a model of the structure of an atom.
- **Explain** how compounds affect an atom's stability.
- **Contrast** covalent and ionic bonds.

VOCABULARY

matter
mass
element
atom
nucleus
proton
neutron
atomic number
mass number
electron
orbital
isotope
compound
chemical bond
covalent bond
molecule
ion
ionic bond

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; *weight* is defined as the force produced by gravity acting on mass. The same mass would have less weight on the moon than it would on Earth because the moon exerts less force on the object than the Earth does.

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.

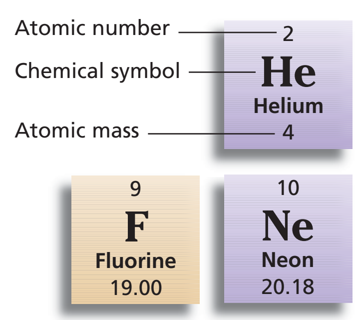
ELEMENTS AND ATOMS

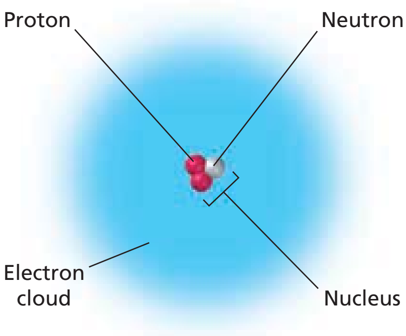
Elements are substances that cannot be broken down chemically into simpler kinds of matter. More than 100 elements have been identified, though fewer than 30 are important to living things. In fact, more than 90 percent of the mass of all kinds of living things is composed of combinations of just four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

Information about the elements is summarized on a chart known as the *periodic table,* which appears in the Appendix. Each element has a different chemical symbol. A chemical symbol consists of one, two, or three 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, such as Cl for chlorine. Most of the other symbols are derived from the Latin names of elements. One example is sodium's symbol, Na, from the Latin word *natrium.*

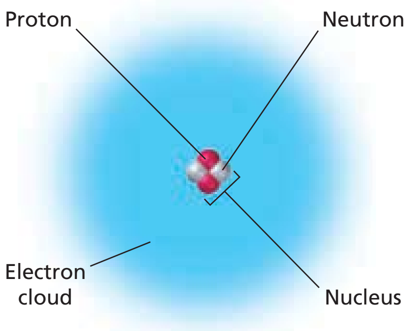
FIGURE 2-1

The periodic table lists information about the elements, including the atomic number, the chemical symbol, and the atomic mass for each element. A complete periodic table can be found in the Appendix.





Helium-3



Helium-4

FIGURE 2-2

Most scientists consider the electron cloud model, shown above, to be the most accurate model of an atom. Here the models show the difference between elements and isotopes. Helium-3 has two protons and one neutron, while Helium-4 has two protons and two neutrons.

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 structure cannot be directly observed. However, scientists have developed models that describe the structure of the atom. One model is shown in Figure 2-2.

The Nucleus

The central region, or **nucleus,** makes up the bulk of the mass of the atom and consists of two kinds of subatomic particles, a **proton** and a neutron. The proton is positively charged and the neutron has no charge. 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. The **mass number** of an atom is equal to the total number of protons and neutrons of the atom. The mass number of fluorine is 19, which indicates that each atom of fluorine has 10 neutrons.

Electrons

In an atom, the number of positively charged protons is balanced by an equal number of small, negatively charged particles called **electrons.** The net electrical charge of an atom is zero. Electrons are high-energy particles that have very little mass. They move about the nucleus at very high speeds and are located in orbitals. An **orbital** is a three-dimensional region around a nucleus that indicates the probable location of an electron. Electrons in orbitals that are farther away from the nucleus have greater energy than electrons that are in orbitals closer to the nucleus. When all orbitals are combined, there is a cloud of electrons surrounding the nucleus, as shown in Figure 2-2.

Orbitals correspond to specific energy levels. Each energy level corresponds to a group of orbitals that can hold only a certain, total number of electrons. For example, the orbital that corresponds to the first energy level can hold only two electrons. The first energy level is the highest energy level for the elements hydrogen and helium. There are four orbitals in the second energy level, and that energy level can hold up to eight total electrons, with a maximum of two electrons in each orbital.

Isotopes

All atoms of an element have the same number of protons. However, all atoms of an element do not necessarily have the same number of neutrons. Atoms of the same element that have a different number of neutrons are called **isotopes.** Additional neutrons change the mass of the element. Most elements are made up of a mixture of isotopes, as shown in Figure 2-2. The *average atomic mass* of an element takes into account the relative amounts of each isotope in the element, and this average is the mass found in the periodic table.

SCILINKS.
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Topic: Atomic Structures
Keyword: HM60119

COMPOUNDS

Under natural conditions, most elements do not exist alone; atoms of most elements can readily combine with the same or different atoms or elements to make compounds. **Compounds** are made up of atoms of two or more elements in fixed proportions. A chemical formula shows the kinds and proportions of atoms of each element that forms a particular compound. For example, water's chemical formula, H_2O, shows that the atoms always combine in a proportion of two hydrogen (H) atoms to one oxygen (O) atom.

The physical and chemical properties differ between the compounds and elements that compose them. 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 at room temperature, they form liquid H_2O. How elements combine and form compounds depends on the number and arrangement of electrons in their orbitals. An atom is chemically stable when the orbitals that correspond to its highest energy level are filled with the maximum number of electrons. Some elements, such as helium and neon, consist of atoms that have the maximum number of electrons in the orbitals of their highest energy levels. These elements, also called *noble* or *inert elements,* do not react with other elements under normal conditions.

Most atoms are not stable in their natural state, so they tend to react with other atoms in different ways to become more stable. Carbon, nitrogen, and oxygen atoms have unfilled orbitals that correspond to their highest energy levels. Similar to these elements, most elements tend to interact with other atoms to form chemical bonds. **Chemical bonds** are the attractive forces that hold atoms together.

Covalent Bonds

A **covalent bond** forms when two atoms share one or more pairs of electrons. For example, water is made up of one oxygen atom and two hydrogen atoms held together by covalent bonds. In Figure 2-3, step 1, an atom of hydrogen needs a second electron to achieve stability. Having two electrons in the orbital that corresponds to hydrogen's highest energy level allows the atom to be more stable. The oxygen atom needs two more electrons to give it a stable arrangement of eight electrons, which fill oxygen's orbitals to its highest energy level. Thus, hydrogen atoms and oxygen atoms share pairs of electrons in a ratio of two atoms of hydrogen to one atom of oxygen. The resulting stable compound, H_2O (water), is shown in step 2.

A **molecule** is the simplest part of a substance that retains all of the properties of that substance and can exist in a free state. For example, one molecule of the compound water is H_2O, and one molecule of oxygen gas is O_2. Some molecules that biologists study are large and complex.

Word Roots and Origins

compound

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

FIGURE 2-3

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

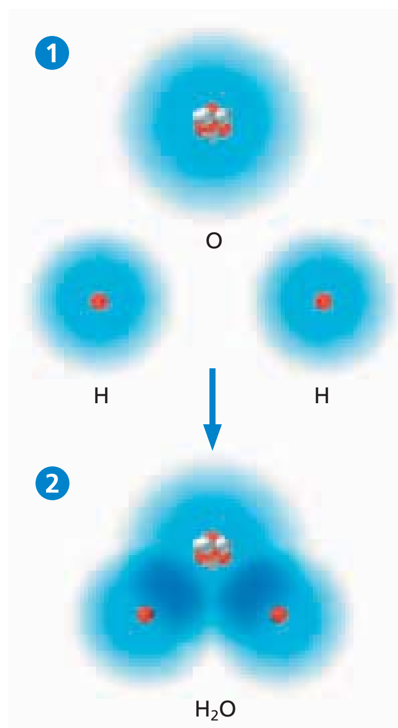
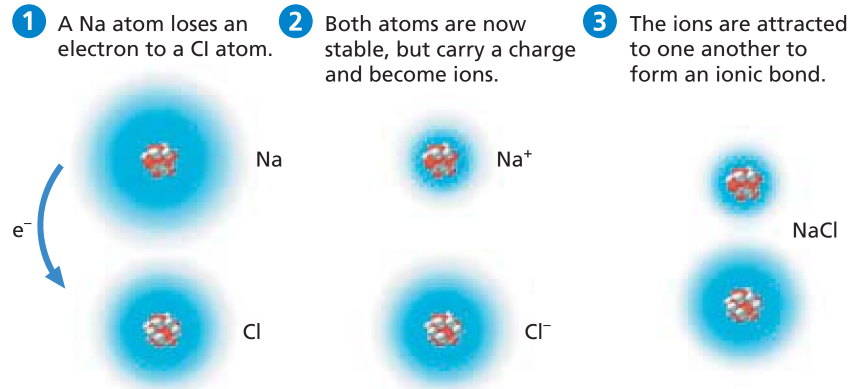


FIGURE 2-4

By losing its outermost electron (e^-), a sodium atom becomes a 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

In Figure 2-4, step 1, both sodium and chlorine atoms have unfilled outermost energy levels and are therefore reactive. Both atoms achieve stability in the presence of one another. The one outer electron (e^-) of a sodium atom is transferred to a chlorine atom. This transfer makes both atoms more stable than they were before. The orbitals that correspond to the sodium atom's new outermost energy level are 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^+.

Chlorine, in step 2, gained an electron from a sodium atom. The chlorine atom now has eight electrons in its orbitals that correspond to its outermost energy level. This makes the chlorine atom more stable. With this additional electron, chlorine becomes a negatively charged ion 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, shown in step 3, is an ionic compound and is familiar to you as common table salt.

SECTION 1 REVIEW

1. What is matter?
2. What is the relationship between elements and atoms?
3. Describe the arrangement within energy levels of the six electrons of an atom of carbon.
4. How are isotopes of the same element alike?
5. How can we predict which elements are reactive under normal conditions and which are unreactive?
6. Distinguish between covalent and ionic bonds.

CRITICAL THINKING

7. **Distinguishing Differences** Explain why the terms *mass* and *weight* should not be used interchangeably.
8. **Applying Information** Classify each of the following as an element or a compound: HCl, CO_2, Cl, Li, and H_2O.
9. **Applying Information** Given that elements are pure substances, how many types of atoms make up the structure of a single element? Explain your answer.

ENERGY

All living things use energy. The amount of energy in the universe remains the same over time, but energy can change from one form to another. It is the transfer 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

OBJECTIVES

- **Describe** the physical properties of each state of matter.
- **Describe** the role of reactants and products in chemical reactions.
- **Explain** the relationship between enzymes and activation energy.
- **Explain** how oxidation and reduction reactions are linked.

VOCABULARY

energy
chemical reaction
reactant
product
metabolism
activation energy
catalyst
enzyme
redox reaction
oxidation reaction
reduction reaction

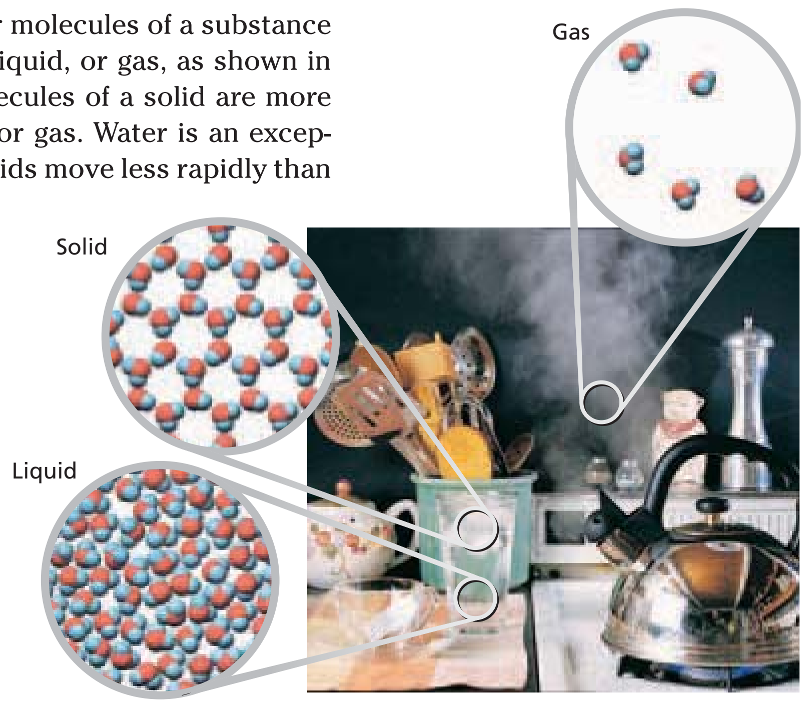
ENERGY AND MATTER

Scientists define **energy** as the ability to do work. 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). Some forms of energy important to biological systems include chemical energy, thermal energy, electrical energy, and mechanical energy. Inside any single organism, energy may be converted from one form to another. For example, after you eat a meal, your body changes 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 motion of and spacing between atoms or molecules of a substance determine the substance's state: solid, liquid, or gas, as shown in Figure 2-5. In general, the atoms or molecules of a solid are more closely linked together than in a liquid or gas. Water is an exception to this, as will be described later. Solids move less rapidly than the particles that make up a liquid or a gas. A solid maintains a fixed volume and shape. A liquid maintains a fixed volume, but its particles move more freely than those of a solid, which gives 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. Thermal energy must be added to the substance to cause a substance to change states.

FIGURE 2-5
Matter exists as solids, liquids, and gases as shown below with water.



ENERGY AND CHEMICAL REACTIONS

In a **chemical reaction,** one or more substances change to produce one or more different substances. Energy is absorbed or released when chemical bonds are broken and new ones are formed. Living things undergo many thousands of chemical reactions every day. Reactions can vary from highly complex to very simple. The chemical reaction in Figure 2-6 takes place in your blood. Carbon dioxide is taken up from body cells and into the blood when it crosses the thin capillary walls. The carbon dioxide reacts with water in the blood to form carbonic acid. Carbon dioxide is then released into the lung's alveoli and exhaled when the carbonic acid breaks down to carbon dioxide and water.

If the reaction proceeds in only one direction, the **reactants** are shown on the left side of the equation. In the reaction in Figure 2-6, the reactants are carbon dioxide (CO_2) and water (H_2O). In a chemical reaction, bonds present in the reactants are broken, the elements are rearranged, and new compounds are formed as the products. The **products** of this reaction are shown on the right side. In this reaction, the product is carbonic acid (H_2CO_3). Notice that the number of each kind of atom must be the same on either side of the arrow. Some chemical reactions can proceed in either direction and a two-direction arrow ($\rightleftharpoons$) is used. For example, the equation in Figure 2-6 is reversible and can be written as $CO_2 + H_2O \rightleftharpoons H_2CO_3$.

The energy your body needs is provided by the sugars, proteins, and fats found in foods. Your body continuously undergoes a series of chemical reactions in which these energy-supplying substances are broken down into carbon dioxide, water, and other products. In this process, energy is released for use by your body to build and maintain body cells, tissues, and organs. **Metabolism** (MUH-TAB-uh-LIZ-uhm) is the term used to describe all of the chemical reactions that occur in an organism.

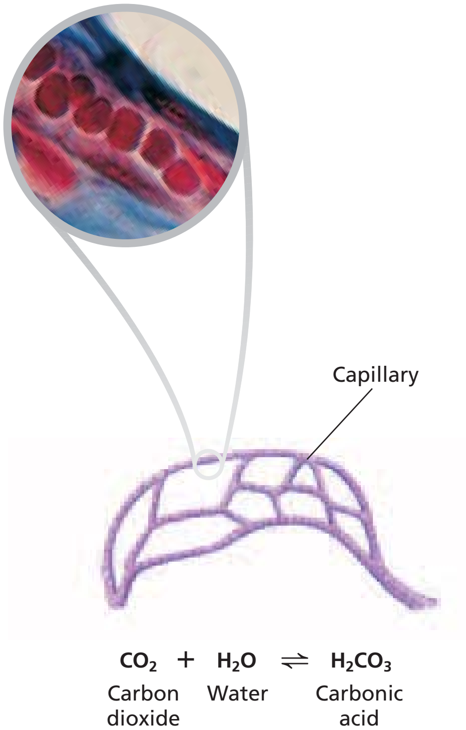


FIGURE 2-6

Chemical reactions occur in the human body. The chemical reaction shown above takes place in capillaries. Because the products of the reaction remain in the blood, the reaction is reversible and is written as: $CO_2 + H_2O \rightleftharpoons H_2CO_3$.

Activation Energy

For most chemical reactions 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 large. Figure 2-7 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 to take place, as shown in Figure 2-7. A reaction in the presence of the correct catalyst will proceed spontaneously or with the addition of a small amount of energy. In living things enzymes act as catalysts. An **enzyme** is a protein or RNA molecule that speeds up metabolic reactions without being permanently changed or destroyed.

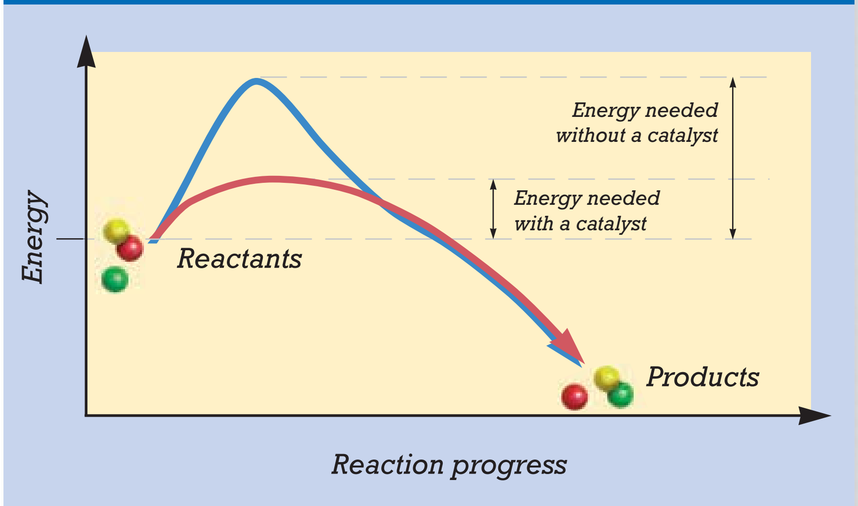


FIGURE 2-7
The blue curve shows the activation energy that must be supplied before this reaction can begin. The activation energy can be reduced, as shown by the red curve, by adding a catalyst.

Oxidation-Reduction Reactions

You know that there is a constant transfer 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 oxidation-reduction reactions, or **redox reactions.** In an **oxidation** (AHKS-i-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 2-4. Thus, the sodium atom undergoes oxidation to form a 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, small and large marshmallows, and raisins

Procedure
Use large marshmallows to represent chlorine, small marshmallows to represent sodium, raisins to represent electrons, and toothpicks to represent bonds or orbital place holders. Make models of Na, Cl, Na^+, Cl^-, and 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 REVIEW

1. Name and describe the physical properties of the three states of matter.
2. Explain the roles of reactants and products in a chemical reaction.
3. Describe the effect of an enzyme on the activation energy in a chemical reaction.
4. Enzymes are biological catalysts. Explain what they do in living systems.
5. Why does a reduction reaction always accompany an oxidation reaction?

CRITICAL THINKING

6. **Analyzing Concepts** Living things need a constant supply of energy. Explain why.
7. **Analyzing Graphics** Carbonic anhydrase is the enzyme that catalyzes the chemical reaction illustrated in Figure 2-6. What effect might a molecule that interferes with the action of carbonic anhydrase have on your body?
8. **Analyzing Information** In a reduction reaction, the reduced atom gains one or more electrons. Why is this reaction called a reduction?

Science in Action

Is There Water on Mars?

Do other living organisms share our solar system? One way to discover a possible answer to this age-old question is to search for the presence of water on other planets. Water is essential for life on Earth, so where there is water, there might be life.

NASA's exploration rover *Opportunity*

HYPOTHESIS: Water Exists on Mars

Scientists at the National Aeronautics and Space Administration (NASA) have sent orbiters, (reusable spacecraft designed to transport people and cargo) between Earth and Mars. Recent orbiters to be sent to Mars include NASA's *Mars Global Surveyor (MGS)* and *Mars Odyssey*. These missions revealed boulders, dust, canyons, and tall volcanic peaks. Some of the most exciting images revealed gullies carved into the Martian landscape. The appearance of these gullies led geologists to hypothesize that the gullies had been carved by running water within the past few million years.

Why is the presence of water on Mars so intriguing? On our planet, where there is water, there is life. For now, scientists are assuming that life-forms on Mars would have the same dependence on water.

METHODS: Image and Analyze Martian Rock Samples

In the summer of 2003, NASA scientists launched *Spirit* and *Opportunity*, two Mars exploration rovers. The job of these two rovers was to take small-scale geologic surveys of surrounding rocks and soil and to search for ancient traces of water. These rovers landed in regions near the Martian equator that may have held water at one time.

RESULTS: Water and Minerals That Can Form in Water Are Present on Mars

The images sent back by the *Odyssey* and *MGS* orbiters reveal that water covers large areas of Mars' polar regions as well as some large areas at its equator. The water is almost certainly frozen in the form of dusty snowpacks, which may occur largely as an icy soil layer. These icepacks may resemble the permafrost of Earth's polar regions.

In addition, *Opportunity* detected the presence of hematite at its landing site, the Meridiani Planum, an area on Mars that was thought to have been a shallow lake at one time. Hematite is a mineral that often forms in pools of standing water on Earth but can also form as a result of volcanic activity. *Opportunity* also found strong evidence that the rocks at Meridiani Planum were once sediments that were laid down by liquid water. This discovery also gives greater weight to the hypothesis that Mars was once a habitat for microbial life.

CONCLUSION: Mars Once Had Water

Chances are that the current mission to Mars will not determine whether life ever started on the planet, but scientists are hopeful that they will have an answer someday. Human exploration of Mars is already being planned. Astronauts would be able to carry out many experiments that robots cannot do.

This picture was taken by one of the rovers that explored Mars.

REVIEW

1. Why did geologists initially hypothesize that there might have been water on Mars?
2. What did the images from NASA orbiters and the exploration rovers in 2003 reveal?
3. **Critical Thinking** Explain why the existence of hematite may not be the best indicator of water on Mars.

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SECTION 3

OBJECTIVES

- **Describe** the structure of a water molecule.
- **Explain** how water's polar nature affects its ability to dissolve substances.
- **Outline** the relationship between hydrogen bonding and the different properties of water.
- **Identify** the roles of solutes and solvents in solutions.
- **Differentiate** between acids and bases.

VOCABULARY

polar
hydrogen bond
cohesion
adhesion
capillarity
solution
solute
solvent
concentration
saturated solution
aqueous solution
hydroxide ion
hydronium ion
acid
base
pH scale
buffer

WATER AND SOLUTIONS

Compare the body of a jellyfish with your own body. A jellyfish would die if it was removed from its watery environment. Yet you can live on the driest parts of Earth. Jellyfish and humans seem unlike each other, yet the bodies of both are made of cells that consist mostly of water. The chemical reactions of all living things take place in the aqueous environment of the cell. Water has several unique properties that make it one of the most important compounds found in living things.

POLARITY

Many of water's biological functions stem from its chemical structure. Recall that in the water molecule, H_2O, the hydrogen and oxygen atoms share electrons to form covalent bonds. However, these atoms do not share the electrons equally. The oxygen atom has a greater ability to attract electrons to it because it pulls hydrogen's electrons towards its nucleus. As a result, as shown in Figure 2-8, the region of the molecule where the oxygen atom is located has a partial negative charge, denoted with a δ^-, while the regions of the molecule where each of the two hydrogen atoms are located have partial positive charges, each of which are denoted with a δ^+. Thus, even though the total charge on a water molecule is neutral, the charge is unevenly distributed across the water molecule. Because of this uneven distribution of charge, water is called a **polar** compound.

Notice also in Figure 2-8 that the three atoms in a water molecule are not arranged in a straight line as you might expect. Rather, the two hydrogen atoms bond with the single oxygen atom at an angle.

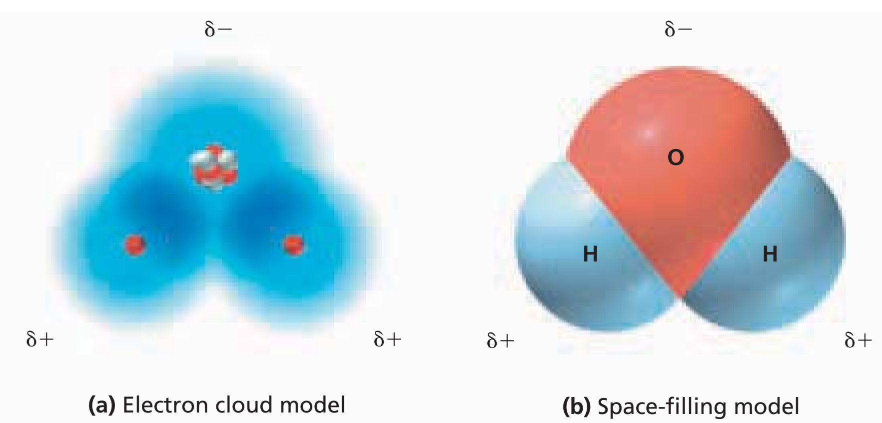
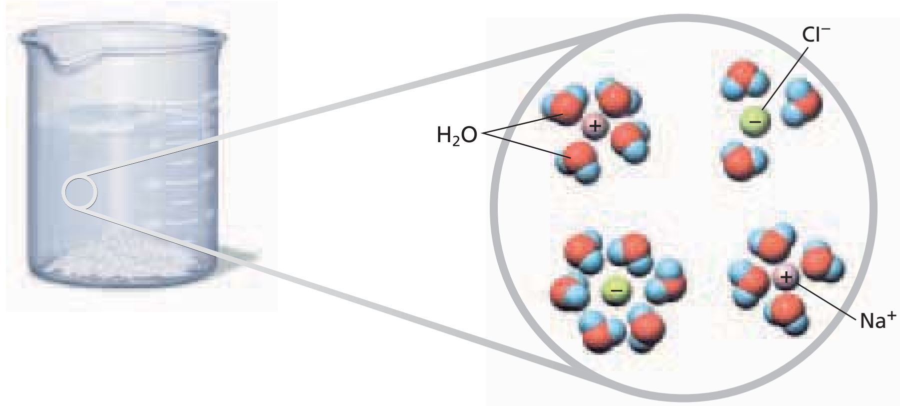


FIGURE 2-8

The oxygen region of the water molecule is weakly negative, and the hydrogen regions are weakly positive. Notice the different ways to represent water, H_2O. You are familiar with the electron cloud model (a). The space-filling model (b) shows the three-dimensional structure of a molecule.

FIGURE 2-9

The positive region of a water molecule attracts the negative region of an ionic compound, such as the Cl^- portion of NaCl. Similarly, the negative region of the water molecule attracts the positive region of the compound—the Na^+ portion of NaCl. As a result, NaCl breaks apart, or dissolves, in water.



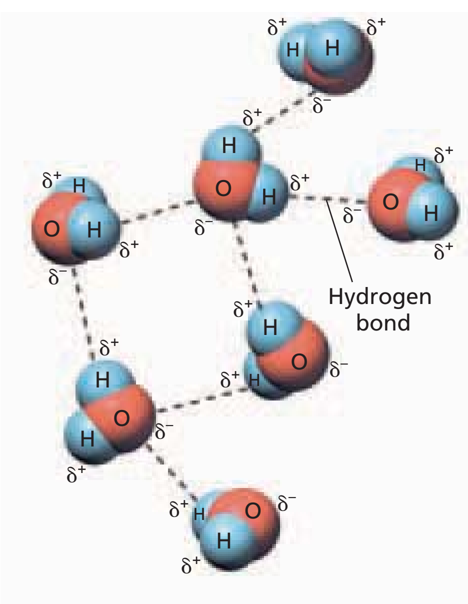
Solubility of Water

The polar nature of water allows it to dissolve polar substances, such as sugars, ionic compounds, and some proteins. Water does not dissolve nonpolar substances, such as oil because a weaker attraction exists between polar and nonpolar molecules than between two polar molecules. Figure 2-9 shows how water dissolves the ionic compound sodium chloride, NaCl. In your body, ions, such as sodium and chloride, are essential to bodily functions, such as muscle contraction and transmission of impulses in the nervous system. In fact, dissolved, or dissociated ions, are present in all of the aqueous solutions found in living things and are important in maintaining normal body functions.

HYDROGEN BONDING

FIGURE 2-10

The dotted lines in this figure represent hydrogen bonds. A hydrogen bond is a force of attraction between a hydrogen atom in one molecule and a negatively charged region or atom in a second molecule.



The polar nature of water also causes water molecules to be attracted to one another. As is shown in Figure 2-10, the positively charged region of one water molecule is attracted to the negatively charged region of another water molecule. This attraction is called a hydrogen bond. A **hydrogen bond** is the force of attraction between a hydrogen molecule with a partial positive charge and another atom or molecule with a partial or full negative charge. Hydrogen bonds in water exert an attractive force strong enough so that water "clings" to itself and some other substances.

Hydrogen bonds form, break, and reform with great frequency. However, at any one time, a great number of water molecules are bonded together. The number of hydrogen bonds that exist depends on the state that water is in. If water is in its solid state all its water molecules are hydrogen bonded and do not break. As water liquifies, more hydrogen bonds are broken than are formed, until an equal number of bonds are formed and broken. Hydrogen bonding accounts for the unique properties of water, some of which we will examine further. These properties include cohesion and adhesion, the ability of water to absorb a relatively large amount of energy as heat, the ability of water to cool surfaces through evaporation, the density of ice, and the ability of water to dissolve many substances.

Cohesion and Adhesion

Water molecules stick to each other as a result of hydrogen bonding. An attractive force that holds molecules of a single substance together is known as **cohesion.** Cohesion due to hydrogen bonding between water molecules contributes to the upward movement of water from plant roots to their leaves.

Related to cohesion is the *surface tension* of water. The cohesive forces in water resulting from hydrogen bonds cause the molecules at the surface of water to be pulled downward into the liquid. As a result, water acts as if it has a thin "skin" on its surface. You can observe water's surface tension by slightly overfilling a drinking glass with water. The water will appear to bulge above the rim of the glass. Surface tension also enables small creatures such as spiders and water-striders to run on water without breaking the surface.

Adhesion is the attractive force between two particles of different substances, such as water molecules and glass molecules. A related property is **capillarity** (KAP-uh-LER-i-tee), which is the attraction between molecules that results in the rise of the surface of a liquid when in contact with a solid. Together, the forces of adhesion, cohesion, and capillarity help water rise through narrow tubes against the force of gravity. Figure 2-11 shows cohesion and adhesion in the water-conducting tubes in the stem of a flower.

Temperature Moderation

Water has a high heat capacity, which means that water can absorb or release relatively large amounts of energy in the form of heat with only a slight change in temperature. This property of water is related to hydrogen bonding. Energy must be absorbed to break hydrogen bonds, and energy is released as heat when hydrogen bonds form. The energy that water initially absorbs breaks hydrogen bonds between molecules. Only after these hydrogen bonds are broken does the energy begin to increase the motion of the water molecules, which raises the temperature of the water. When the temperature of water drops, hydrogen bonds reform, which releases a large amount of energy in the form of heat.

Therefore, during a hot summer day, water can absorb a large quantity of energy from the sun and can cool the air without a large increase in the water's temperature. At night, the gradually cooling water warms the air. In this way, the Earth's oceans stabilize global temperatures enough to allow life to exist. Water's high heat capacity also allows organisms to keep cells at an even temperature despite temperature changes in the environment.

As a liquid evaporates, the surface of the liquid that remains behind cools down. A relatively large amount of energy is absorbed by water during evaporation, which significantly cools the surface of the remaining liquid. Evaporative cooling prevents organisms that live on land from overheating. For example, the evaporation of sweat from a person's skin releases body heat and prevents overheating on a hot day or during strenuous activity.

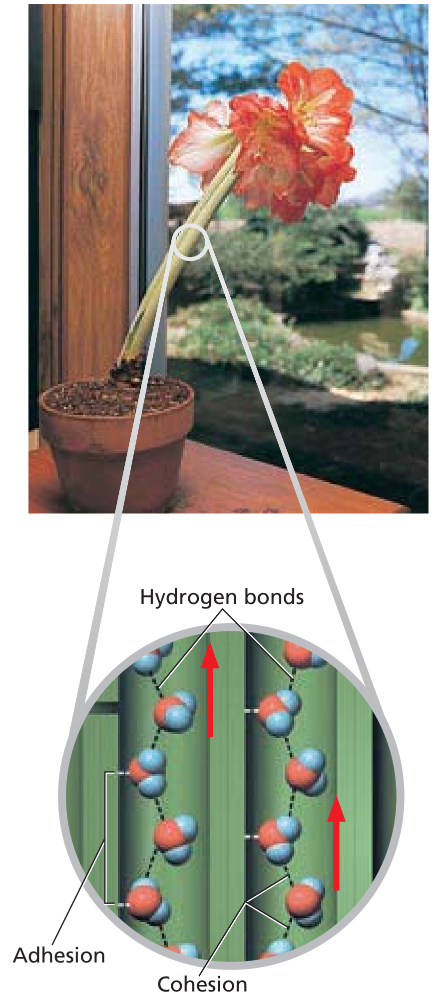


FIGURE 2–11
Cohesion, adhesion, and capillarity contribute to the upward movement of water from the roots of plants.

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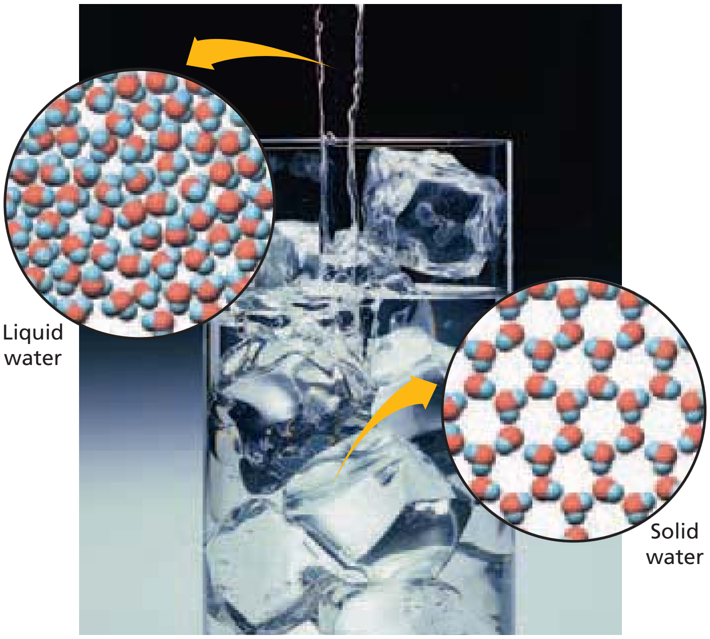


FIGURE 2-12

Ice (solid water) is less dense than liquid water because of the structure of ice crystals. The water molecules in ice are bonded to each other in a way that creates large amounts of open space between the molecules, relative to liquid water.

Density of Ice

Unlike most solids, which are denser than their liquids, solid water is less dense than liquid water. This property is due to the shape of the water molecule and hydrogen bonding. The angle between the hydrogen atoms is quite wide. So, when water forms solid ice, the angles in the molecules cause ice crystals to have large amounts of open space, as shown in Figure 2-12. This open space lattice structure causes ice to have a low density.

Because ice floats on water, bodies of water such as ponds and lakes freeze from the top down and not the bottom up. Ice insulates the water below from the cold air, which allows fish and other aquatic creatures to survive under the icy surface.

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. A **solute** (SAHL-YOOT) is a substance dissolved in the solvent. 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 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 is 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. 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; in fact, most chemical reactions that occur in the body occur in aqueous solutions.

Word Roots and Origins

solvent

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

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 use the terms *acid* and *base*?

Ionization of Water

As water molecules move about, they bump into one another. Some of these collisions are strong enough to result in a chemical change: one water molecule loses a proton (a hydrogen nucleus), and the other gains this proton. This reaction really occurs in two steps. First, one molecule of water pulls apart another water molecule, or dissociates, into two ions of opposite charge:

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

The OH^- ion is known as the **hydroxide ion.** The free H^+ ion can react with another water molecule, as shown in the equation below.

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

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.** For example, when hydrogen chloride gas, HCl, is dissolved in water, its molecules dissociate to form hydrogen ions, H^+, and chloride ions, Cl^-, as is shown in the equation below.

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

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; however, never taste a substance to test it for acidity. In concentrated forms, they are highly corrosive to some materials, as you can see in Figure 2-13.

Bases

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

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

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.

FIGURE 2-13

Sulfur dioxide, SO_2, which is produced when fossil fuels are burned, reacts with water in the atmosphere to produce acid precipitation. Acid precipitation, or acid rain, can make lakes and rivers too acidic to support life and can even corrode stone, such as the face of this statue.

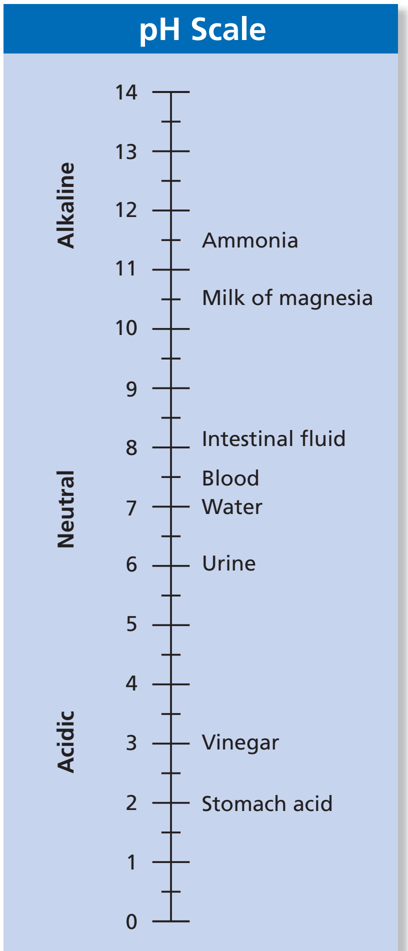


FIGURE 2-14

Some of your body fluids are acidic, and others are alkaline. A solution with a pH above 7 is alkaline, and a solution with a pH below 7 is acidic. Each unit on the pH scale reflects a 10-fold change in acidity or alkalinity.

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; however, never taste a substance to test for alkalinity. 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 the product of a reaction between a base and a fat.

pH

Scientists have developed a scale for comparing the relative concentrations of hydronium ions and hydroxide ions in a solution. This scale is called the **pH scale,** and it ranges from 0 to 14, as shown in Figure 2-14. 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 10-fold change in the acidity or alkalinity. For example, urine has 10 times the H_3O^+ ions at a pH of 6 than water does at a pH of 7. Vinegar, has 1,000 times more H_3O^+ ions at a pH of 3 than urine at a pH of 6, and 10,000 times more H_3O^+ ions than water at a pH of 7. 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 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 2-14 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 in a normal healthy body.

SECTION 3 REVIEW

1. Illustrate the structure of a water molecule by drawing a space-filling model.
2. Why is water called a polar molecule?
3. Identify the properties of water that are important for life to be able to exist.
4. Identify the solute and solvent in a hot chocolate solution that is made of chocolate syrup and warm milk.
5. Why does pure water have a neutral pH?
6. Outline a reason why the control of pH is important in living systems.

CRITICAL THINKING

7. **Recognizing Relationships** What is the relationship among hydrogen bonds and the forces of cohesion, adhesion, and capillarity?
8. **Applying Information** The active ingredient in aspirin is acetylsalicylic acid. Why would doctors recommend buffered aspirin, especially for those with a "sensitive" stomach?
9. **Analyzing Graphics** All units on the pH scale in Figure 2-14 look equivalent, but they are not. Why is the scale drawn as though they are?

CHAPTER HIGHLIGHTS

SECTION 1 Composition of Matter

- Matter is anything that occupies space and has mass.
- Elements are made of a single kind of atom and cannot be broken down by chemical means into simpler substances.
- Atoms are composed of protons, neutrons, and electrons. Protons and neutrons make up the nucleus of the atom. Electrons move about the nucleus in orbitals.
- 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. An atom achieves stability when the orbitals that correspond to its highest energy level are filled with the maximum number of electrons.
- A covalent bond is formed when two atoms share electrons.
- 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

matter (p. 31)	**proton** (p. 32)	**orbital** (p. 32)	**molecule** (p. 33)
mass (p. 31)	**neutron** (p. 32)	**isotope** (p. 32)	**ion** (p. 34)
element (p. 31)	**atomic number** (p. 32)	**compound** (p. 33)	**ionic bond** (p. 34)
atom (p. 32)	**mass number** (p. 32)	**chemical bond** (p. 33)	
nucleus (p. 32)	**electron** (p. 32)	**covalent bond** (p. 33)	

SECTION 2 Energy

- Addition of energy to a substance can cause its state to change from a solid to a liquid and from a liquid to a gas.
- Reactants are substances that enter chemical reactions. Products are substances produced by chemical reactions.
- Enzymes lower the amount of activation energy necessary for a reaction to begin in living systems.
- A chemical reaction in which electrons are exchanged between atoms is called an oxidation-reduction reaction.

Vocabulary

energy (p. 35)	**product** (p. 36)	**catalyst** (p. 36)	**oxidation reaction** (p. 37)
chemical reaction (p. 36)	**metabolism** (p. 36)	**enzyme** (p. 36)	**reduction reaction** (p. 37)
reactant (p. 36)	**activation energy** (p. 36)	**redox reaction** (p. 37)	

SECTION 3 Water and Solutions

- The two hydrogen atoms and one oxygen atom that make up a water molecule are arranged at an angle to one another.
- Water is a polar molecule. The electrons in the molecule are shared unevenly between hydrogen and oxygen. This polarity makes water effective at dissolving other polar substances.
- Hydrogen bonding accounts for most of the unique properties of water.
- The unique properties of water include the ability to dissolve many substances, cohesion and adhesion, the ability to absorb a relatively large amount of energy as heat, the ability to cool surfaces through evaporation, and the low density of ice.
- A solution consists of a solute dissolved in a solvent.
- Water ionizes into hydronium ions and hydroxide ions.
- Acidic solutions contain more hydronium ions than hydroxide ions. Basic solutions contain more hydroxide ions than hydronium ions.
- Buffers are chemicals that neutralize the effects of adding small amounts of either an acid or a base to a solution.

Vocabulary

polar (p. 39)	**solution** (p. 42)	**aqueous solution** (p. 42)	**pH scale** (p. 44)
hydrogen bond (p. 40)	**solute** (p. 42)	**hydroxide ion** (p. 43)	**buffer** (p. 44)
cohesion (p. 41)	**solvent** (p. 42)	**hydronium ion** (p. 43)	
adhesion (p. 41)	**concentration** (p. 42)	**acid** (p. 43)	
capillarity (p. 41)	**saturated solution** (p. 42)	**base** (p. 44)	

CHAPTER REVIEW

USING VOCABULARY

1. For each pair of terms, explain how the meanings of the terms differ.
   a. *oxidation* and *reduction*
   b. *reactants* and *products*
   c. *acid* and *base*
2. Explain the relationship between electrons, neutrons, and protons.
3. Choose the term that does not belong in the following group, and explain why it does not belong: *element, compound, chemical bonds,* and *adhesion*.
4. **Word Roots and Origins** The term *catalyst* comes from the Greek *katalysis,* meaning "dissolution." Give reasons that this term is appropriate in describing the function of enzymes.

UNDERSTANDING KEY CONCEPTS

5. **Differentiate** between the mass and the weight of an object.
6. **Name** the subatomic particles that are found in the nucleus of an atom.
7. **Describe** the arrangement within energy levels of the seven electrons of an atom of nitrogen.
8. **Describe** how compounds affect an atom's stability.
9. **Differentiate** between covalent and ionic bonds.
10. **Compare** the motion and spacing of the molecules in a solid to the motion and spacing of the molecules in a gas.
11. **Identify** the reactants and the products in the following chemical reaction.

$$A + B \longrightarrow C + D$$

12. **Explain** the relationship between enzymes and activation energy.
13. **Explain** oxidation and reduction in terms of electron transfer and charge.
14. **Describe** the structure of a water molecule.
15. **Outline** what happens when water ionizes.
16. **Describe** how water behaves at its surface and the role hydrogen bonding plays in this behavior.
17. **Identify** the solute(s) and solvent(s) in a cup of instant coffee with sugar.
18. **Name** two ions that are the products of the dissociation of water.
19. **Compare** an acid to a base in terms of the hydroxide ion concentration.
20. **CONCEPT MAPPING** Use the following terms to create a concept map that shows how the properties of water help it rise in plants: *water, hydrogen bonds, cohesion, adhesion, capillarity,* and *plants*.

CRITICAL THINKING

21 **Analyzing Concepts** In nature, the elements oxygen and hydrogen are usually found as gases with the formulas O_2 and H_2. Why? Are they compounds? Are they molecules?

22. **Analyzing Data** The table below 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. Between the melting point and the boiling point, a compound or element exists as a liquid. Below the melting point, a compound or element exists as a solid. Use the table to answer the following questions:
    a. At 20°C and under normal 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	2,330
Argon	−190	−186
Chlorine	−104	−34
Mercury	−39	357
Water	0	100

23. **Recognizing Relationships** Cells contain mostly water. What would happen to the stability of an organism's internal temperature with respect to environmental temperature changes if cells contained mostly oil, which does not have extensive hydrogen bonding?

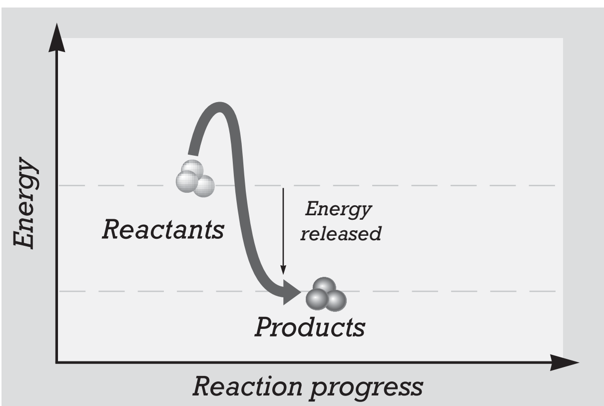
Standardized Test Preparation

DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. The way in which elements bond to form compounds depends on which of the following?
A. the model of the atom
B. the structural formula of the compound
C. the dissociation of the ions in the compound
D. the number and arrangement of electrons in the atoms of the elements

2. If an atom is made up of 6 protons, 7 neutrons, and 6 electrons, what is its atomic number?
F. 6
G. 7
H. 13
J. 19

INTERPRETING GRAPHICS: The graph below shows the energy in a chemical reaction as the reaction progresses. Use the graph to answer the questions that follow.



3. The amount of energy needed for this chemical reaction to begin is shown by the line rising from the reactants. What is this energy called?
A. chemical energy
B. electrical energy
C. activation energy
D. mechanical energy

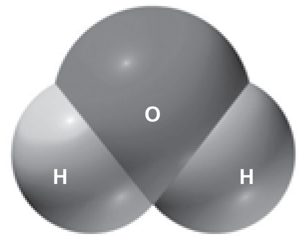
4. Suppose that this reaction needs a catalyst to proceed. In the absence of a catalyst, the activation energy would be which of the following?
F. larger than what is shown
G. the same as what is shown
H. smaller than what is shown
J. not much different from what is shown

5. What is an aqueous solution that contains more hydroxide ions than hydronium ions called?
A. a gas
B. a base
C. a solid
D. an acid

DIRECTIONS: Complete the following analogy.

6. Oxidation : loss :: reduction :
F. win
G. gain
H. take
J. forfeit

INTERPRETING GRAPHICS: The illustration below is a space-filling model of water. Use the model to answer the following question.



7. The water molecule above has partial positive charges on the hydrogen atoms and a partial negative charge on the oxygen atom. What can you conclude from this information and the diagram of the water molecule?
A. Water is an ion.
B. Water is a polar molecule.
C. Water needs a proton and two electrons to be stable.
D. Oxygen atoms and hydrogen atoms have opposite charges.

SHORT RESPONSE

Covalent bonding is a sharing of electrons between atoms. Why do some atoms share electrons?

EXTENDED RESPONSE

Pure water contains equal numbers of hydronium ions and hydroxide ions and is therefore a neutral solution.

Part A What is the initial cause of the dissociation of water molecules into hydrogen and hydroxide ions? Explain the process.

Part B After water dissociates, hydronium ions are formed. Explain this process.

Test TIP When possible use the text in the test to answer other questions. For example use a multiple choice answer to "jump start" your thinking about another question.

INQUIRY LAB

Measuring the Activity of Enzymes in Detergents

OBJECTIVES

- Recognize the function of enzymes in laundry detergents.
- Relate the factors of temperature and pH to the activity of enzymes.

MATERIALS

- safety goggles
- lab apron
- protective gloves
- balance
- graduated cylinder
- glass stirring rod
- 150 mL beaker
- 18 g regular instant gelatin or 1.8 g sugar-free instant gelatin
- 0.7 g Na_2CO_3, sodium carbonate
- tongs or a hot mitt
- 50 mL boiling water
- thermometer
- pH paper
- 6 test tubes
- test-tube rack
- pipet with bulb
- plastic wrap
- tape
- 50 mL beakers (6)
- 50 mL distilled water
- 1 g each of 5 brands of laundry detergent
- wax pencil
- metric ruler

SAFETY

Background

1. Write a definition for the term *enzyme.*
2. From what you know about enzymes, why might enzymes be added to detergents?

Procedure

PART A Making a Protein Substrate

1. CAUTION **Always wear safety goggles, protective gloves, and a lab apron to protect your eyes and clothing.** Put on safety goggles and a lab apron.
2. CAUTION **Use tongs or a hot mitt to handle heated glassware.** Put 18 g of regular (1.8 g of sugar-free) instant gelatin in a 150 mL beaker. Slowly add 50 mL of boiling water to the beaker, and stir the mixture with a stirring rod. Test and record the pH of this solution.
3. CAUTION **Do not touch or taste any chemicals.** Very slowly add 0.7 g of Na_2CO_3 to the hot gelatin while stirring. Note any reaction. Test and record the pH of this solution.
4. CAUTION **Glassware is fragile. Notify the teacher of broken glass or cuts. Do not clean up broken glass or spills with broken glass unless the teacher tells you to do so. Remember to use tongs or a hot mitt to handle heated glassware.** Place 6 test tubes in a test-tube rack. Pour 5 mL of the gelatin-Na_2CO_3 mixture into each tube. Use a pipet to remove any bubbles from the surface of the mixture in each tube. Cover the tubes tightly with plastic wrap and tape. Cool the tubes, and store them at room temperature until you begin Part C. Complete step 11 in Part C.

PART B Designing Your Experiment

5. Based on the objectives for this lab, write a question you would like to explore about enzymes in detergents. To explore the question, design an experiment that uses the materials listed for this lab.
6. Write a procedure for your experiment. Make a list of all the safety precautions you will take. Have your teacher approve your procedure and safety precautions before you begin the experiment.

PART C Conducting Your Experiment

7. CAUTION **Always wear safety goggles and a lab apron to protect your eyes and clothing.** Put on safety goggles and a lab apron.
8. Make a 10 percent solution of each laundry detergent by dissolving 1 g of detergent in 9 mL of distilled water.
9. Set up your experiment. Repeat step 11.
10. Record your data after 24 hours in a data table similar to the one below.

    CAUTION **Know the location of the emergency shower and eyewash station and how to use them. If you get a chemical on your skin or clothing, wash it off at the sink while calling to the teacher. Notify the teacher of a spill. Spills should be cleaned up promptly, according to your teacher's directions. Dispose of solutions, broken glass, and gelatin in the designated waste containers. Do not pour chemicals down the drain or put lab materials in the trash unless your teacher tells you to do so.**
11. Clean up your work area and all lab equipment. Return lab equipment to its proper place. Wash your hands thoroughly before leaving the lab and after finishing all work.

Analysis and Conclusions

1. Suggest a reason for adding Na_2CO_3 to the gelatin solution.
2. Make a bar graph of your data. Plot the amount of gelatin broken down (change in the depth of the gelatin) on the *y*-axis and the type of detergent on the *x*-axis. Use a separate sheet of graph paper.
3. What conclusions did your group infer from the results? Explain.

Further Inquiry

Research other household products that contain enzymes, and find out their role in each of the products.

DATA TABLE

Solution	Date	Observations

CHAPTER 3

BIOCHEMISTRY

All living organisms, such as those seen in this photo, are made up of molecules that contain primarily carbon atoms.

CARBON COMPOUNDS

Although water is the primary medium for life on Earth, most of the molecules from which living organisms are made are based on the element carbon. Carbon's ability to form large and complex molecules has contributed to the great diversity of life.

SECTION 1

OBJECTIVES

- **Distinguish** between organic and inorganic compounds.
- **Explain** the importance of carbon bonding in biological molecules.
- **Identify** functional groups in biological molecules.
- **Summarize** how large carbon molecules are synthesized and broken down.
- **Describe** how the breaking down of ATP supplies energy to drive chemical reactions.

VOCABULARY

organic compound
functional group
monomer
polymer
macromolecule
condensation reaction
hydrolysis
adenosine triphosphate (ATP)

CARBON BONDING

All compounds can be classified in two broad categories: organic compounds and inorganic compounds. **Organic compounds** are made primarily of carbon atoms. Most matter in living organisms that is not water is made of organic compounds. *Inorganic compounds,* with a few exceptions, do not contain carbon atoms.

A carbon atom has four electrons in its outermost energy level. Most atoms become stable when their outermost energy level contains eight electrons. A carbon atom therefore readily forms four covalent bonds with the atoms of other elements. Unlike other elements, however, carbon also readily bonds with other carbon atoms, forming straight chains, branched chains, or rings, as shown in Figure 3-1. This tendency of carbon to bond with itself results in an enormous variety of organic compounds.

In the symbolic shorthand of chemistry, each line shown in Figure 3-1 represents a covalent bond formed when two atoms share a pair of electrons. A bond formed when two atoms share one pair of electrons is called a *single bond*.

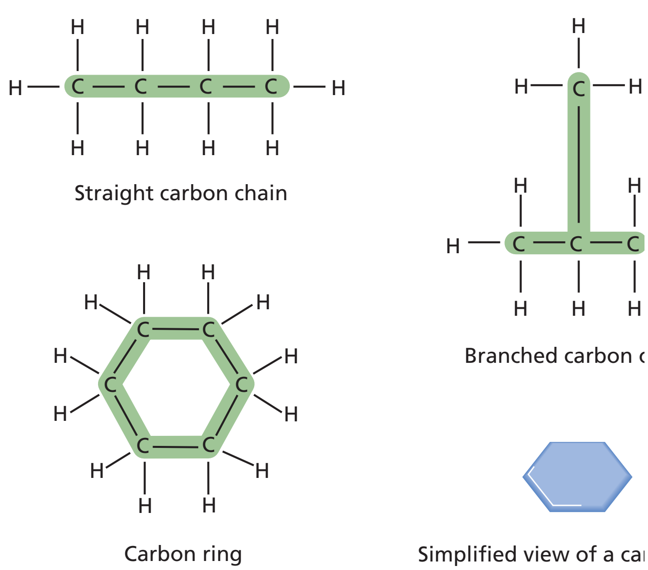
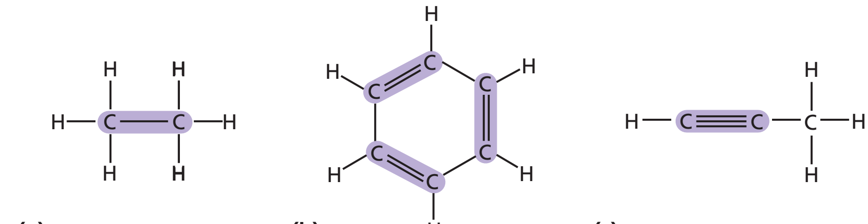


FIGURE 3-1
Carbon can bond in a number of ways to produce molecules of very different shapes, including straight chains (a), branched chains (b), and rings (c) and (d). These structures form the backbone of many different kinds of organic molecules. The carbon ring is shown with all of its atoms (c), and in a simplified version (d) commonly used in this textbook and elsewhere.



(a) (b) (c)

FIGURE 3-2

Carbon atoms can form single (a), double (b), or triple (c) bonds. Organic molecules can have many different shapes and patterns of bonding.

A carbon atom can also share two or even three pairs of electrons with another atom. Figure 3-2b shows a model for an organic compound in which six carbon atoms have formed a ring. Notice that each carbon atom forms four covalent bonds: a single bond with another carbon atom, a single bond with a hydrogen atom, and a double bond with a second carbon atom. In a *double bond*—represented by two parallel lines—atoms share two pairs of electrons. A *triple bond,* the sharing of three pairs of electrons, is represented by three parallel lines in Figure 3-2c.

Quick Lab

Demonstrating Polarity

Materials disposable gloves; lab apron; safety goggles; 3 test tubes; test-tube rack; 6 mL each of cooking oil, ethanol, and water

Procedure

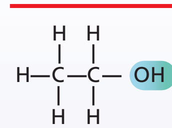
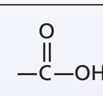
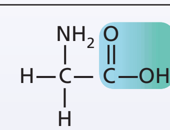
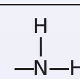
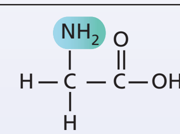
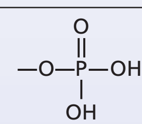
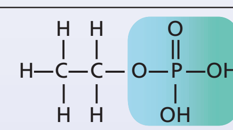
1. Put on disposable gloves, a lab apron, and safety goggles, and then label the test tubes "A," "B," and "C."
2. In test tube A, put 3 mL of water and 3 mL of oil.
3. In test tube B, put 3 mL of ethanol and 3 mL of oil.
4. In test tube C, put 3 mL of water and 3 mL of ethanol.
5. With your middle finger, flick each test tube to mix the contents, and allow each to sit for 10–15 minutes. Record your observations.

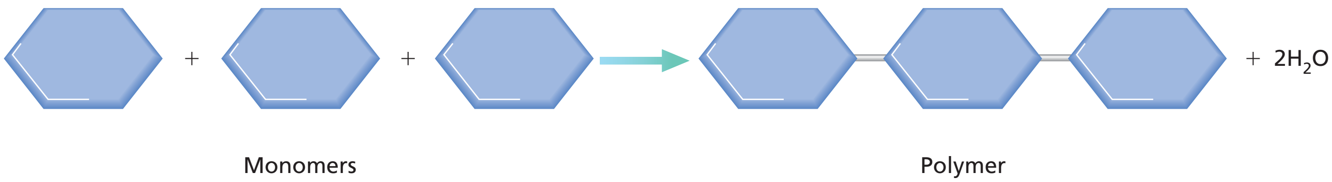
Analysis Polar molecules are soluble in water. How does this activity demonstrate polarity of molecules that contain the —OH group?

FUNCTIONAL GROUPS

In most organic compounds, clusters of atoms, called **functional groups,** influence the characteristics of the molecules they compose and the chemical reactions the molecules undergo. For example, one functional group important to living things, the hydroxyl group, —OH, can make the molecule it is attached to polar. Polar molecules are *hydrophilic* (HIE-droh-FIL-ik), or soluble in water. An *alcohol* is an organic compound with a hydroxyl group attached to one of its carbon atoms. The hydroxyl group makes an alcohol a polar molecule. The alcohol illustrated in the first row in Table 3-1 is ethanol. Other functional groups important to living things are shown in Table 3-1. These functional groups include a carboxyl group, an amino group, and a phosphate group.

TABLE 3-1 *Common Functional Groups*

Functional group	Structural formula	Example
Hydroxyl	—OH	
Carboxyl		
Amino		
Phosphate		



LARGE CARBON MOLECULES

Many carbon compounds are built up from smaller, simpler molecules known as **monomers** (MAH-ne-mers), such as the ones shown in Figure 3-3. As you can also see in Figure 3-3, monomers can bond to one another to form polymers (PAWL-eh-mer). A **polymer** is a molecule that consists of repeated, linked units. The units may be identical or structurally related to each other. Large polymers are called **macromolecules.** There are many types of macromolecules, such as carbohydrates, lipids, proteins and nucleic acids.

Monomers link to form polymers through a chemical reaction called a **condensation reaction.** Each time a monomer is added to a polymer, a water molecule is released. In the condensation reaction shown in Figure 3-4, two sugar molecules, glucose and fructose, combine to form the sugar sucrose, which is common table sugar. The two sugar monomers become linked by a C—O—C bridge. In the formation of that bridge, the glucose molecule releases a hydrogen ion, H^+, and the fructose molecule releases a hydroxide ion, OH^-. The OH^- and H^+ ions that are released then combine to produce a water molecule, H_2O.

In addition to building polymers through condensation reactions, living organisms also have to break them down. The breakdown of some complex molecules, such as polymers, occurs through a process known as hydrolysis (hie-DRAHL-i-sis). In a **hydrolysis** reaction, water is used to break down a polymer. The water molecule breaks the bond linking each monomer. Hydrolysis is the reverse of a condensation reaction. The addition of water to some complex molecules, including polymers, under certain conditions can break the bonds that hold them together. For example, in Figure 3-4 reversing the reaction will result in sucrose breaking down into fructose and glucose.

FIGURE 3-3

A polymer is the result of bonding between monomers. In this example, each monomer is a six-sided carbon ring. The starch in potatoes is an example of a molecule that is a polymer.

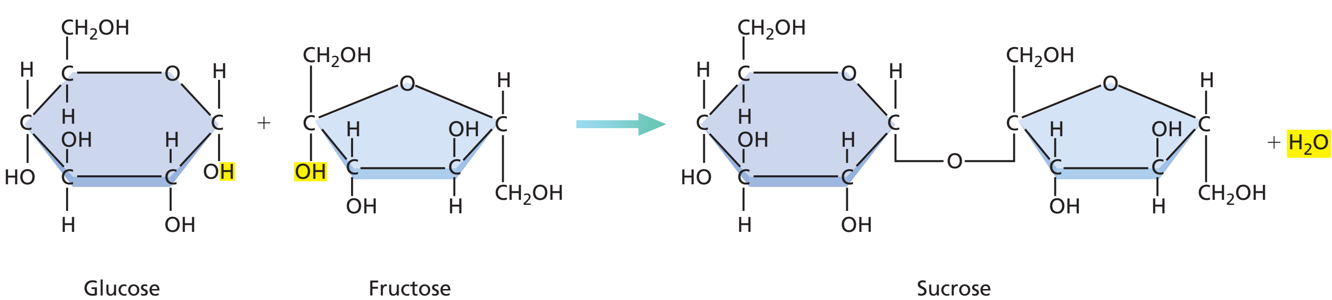
Word Roots and Origins

monomer

from the Greek *mono,* meaning "single or alone," and *meros,* meaning "a part"

FIGURE 3-4

The condensation reaction below shows how glucose links with fructose to form sucrose. One water molecule is produced each time two monomers form a covalent bond.



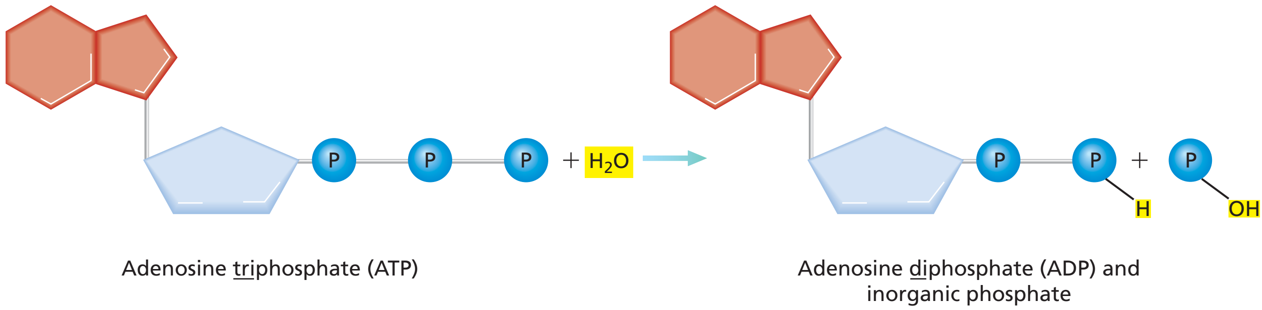


FIGURE 3-5

The hydrolysis of ATP yields adenosine diphosphate (ADP) and inorganic phosphate. In hydrolysis, a hydrogen ion from a water molecule bonds to one of the new molecules, and a hydroxide ion bonds to the other new molecule. Most hydrolysis reactions release energy.

ENERGY CURRENCY

Life processes require a constant supply of energy. This energy is available to cells in the form of certain compounds that store a large amount of energy in their overall structure. One of these compounds is **adenosine** (uh-DEN-uh-SEEN) **triphosphate,** more commonly referred to by its abbreviation, **ATP.**

The left side of Figure 3-5 shows a simplified ATP molecule structure. The 5-carbon sugar, ribose, is represented by the blue carbon ring. The nitrogen-containing compound, adenine, is represented by the 2 orange rings. The three linked phosphate groups, $—PO_4^-$, are represented by the blue circles with a "P." The phospate groups are attached to each other by covalent bonds.

The covalent bonds between the phosphate groups are more unstable than the other bonds in the ATP molecule because the phosphate groups are close together and have negative charges. Thus, the negative charges make the bonds easier to break. When a bond between the phosphate groups is broken, energy is released. This hydrolysis of ATP is used by the cell to provide the energy needed to drive the chemical reactions that enable an organism to function.

Word Roots and Origins

phosphate

from the Latin *phosphor,* meaning "morning star," (morning stars are very bright, similar to phosphorus when it burns) and *ate,* meaning "salt"

SECTION 1 REVIEW

1. How do inorganic and organic compounds differ?
2. How do carbon's bonding properties contribute to the existence of a wide variety of biological molecules?
3. Name four types of functional groups.
4. What role do functional groups play in the molecules in which they are found?
5. How are monomers, polymers, and macromolecules related to each other?
6. How is a polymer broken down?
7. Why is ATP referred to as the "energy currency" in living things?

CRITICAL THINKING

8. **Analyzing Concepts** Humans are about 65 percent water, and tomatoes are about 90 percent water. Yet, water is not a major building block of life. Explain.
9. **Analyzing Concepts** Carbon dioxide, CO_2, contains carbon, yet it is considered to be inorganic. Explain.
10. **Relating Information** Condensation reactions are also referred to as dehydration synthesis. Explain how the name *dehydration synthesis* is descriptive of the process.

MOLECULES OF LIFE

SECTION 2

OBJECTIVES

- **Distinguish** between monosaccharides, disaccharides, and polysaccharides.
- **Explain** the relationship between amino acids and protein structure.
- **Describe** the induced fit model of enzyme action.
- **Compare** the structure and function of each of the different types of lipids.
- **Compare** the nucleic acids DNA and RNA.

VOCABULARY

carbohydrate
monosaccharide
disaccharide
polysaccharide
protein
amino acid
peptide bond
polypeptide
enzyme
substrate
active site
lipid
fatty acid
phospholipid
wax
steroid
nucleic acid
deoxyribonucleic acid (DNA)
ribonucleic acid (RNA)
nucleotide

Four main classes of organic compounds are essential to the life processes of all living things: carbohydrates, lipids, proteins, and nucleic acids. You will see that although these compounds are built primarily from carbon, hydrogen, and oxygen, these atoms occur in different ratios in each class of compound. Each class of compounds has different properties.

CARBOHYDRATES

Carbohydrates are organic compounds composed of carbon, hydrogen, and oxygen in a ratio of about one carbon atom to two hydrogen atoms to one oxygen atom. The number of carbon atoms in a carbohydrate varies. Some carbohydrates serve as a source of energy. Other carbohydrates are used as structural materials. Carbohydrates can exist as monosaccharides, disaccharides, or polysaccharides.

Monosaccharides

A monomer of a carbohydrate is called a **monosaccharide** (MAHN-oh-SAK-uh-RIED). A monosaccharide—or simple sugar—contains carbon, hydrogen, and oxygen in a ratio of 1:2:1. The general formula for a monosaccharide is written as $(CH_2O)_n$, where n is any whole number from 3 to 8. For example, a six-carbon monosaccharide, $(CH_2O)_6$, would have the formula $C_6H_{12}O_6$.

The most common monosaccharides are glucose, fructose, and galactose, as shown in Figure 3-6. Glucose is a main source of energy for cells. Fructose is found in fruits and is the sweetest of the monosaccharides. Galactose is found in milk.

Notice in Figure 3-6 that glucose, fructose, and galactose have the same molecular formula, $C_6H_{12}O_6$, but differing structures. The different structures determine the slightly different properties of the three compounds. Compounds like these sugars, with a single chemical formula but different structural forms, are called *isomers* (IE-soh-muhrz).

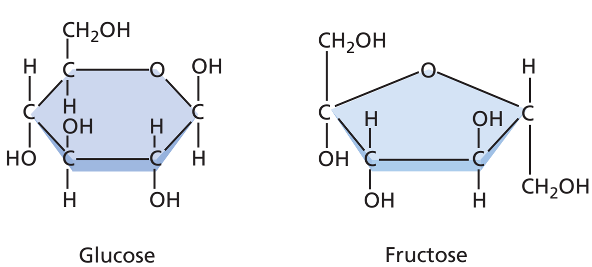


FIGURE 3-6

Glucose, fructose, and galactose have the same chemical formula, but their structural differences result in different properties among the three compounds.

Disaccharides and Polysaccharides

In living things, two monosaccharides can combine in a condensation reaction to form a double sugar, or **disaccharide** (die-SAK-e-RIED). For example in Figure 3-4, the monosaccharides fructose and glucose can combine to form the disaccharide sucrose.

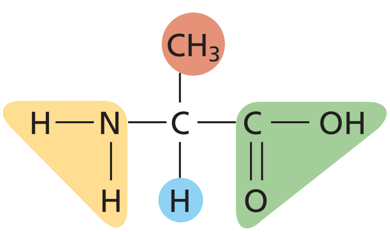
A **polysaccharide** is a complex molecule composed of three or more monosaccharides. Animals store glucose in the form of the polysaccharide *glycogen.* Glycogen consists of hundreds of glucose molecules strung together in a highly branched chain. Much of the glucose that comes from food is ultimately stored in your liver and muscles as glycogen and is ready to be used for quick energy.

Plants store glucose molecules in the form of the polysaccharide *starch.* Starch molecules have two basic forms—highly branched chains that are similar to glycogen and long, coiled, unbranched chains. Plants also make a large polysaccharide called *cellulose.* Cellulose, which gives strength and rigidity to plant cells, makes up about 50 percent of wood. In a single cellulose molecule, thousands of glucose monomers are linked in long, straight chains. These chains tend to form hydrogen bonds with each other. The resulting structure is strong and can be broken down by hydrolysis only under certain conditions.

FIGURE 3-7

(a) Many structures, such as hair and horns are made of proteins. (b) Proteins are made up of amino acids. Amino acids differ only in the type of R group (shown in red) they carry. Polar R groups can dissolve in water, but nonpolar R groups cannot. (c) Amino acids have complex structures, so, in this and other textbooks, they are often simplified into balls.

(a)



(b) Alanine (an amino acid)

(c) Simplified version of amino acid

PROTEINS

Proteins are organic compounds composed mainly of carbon, hydrogen, oxygen, and nitrogen. Like most of the other biological macromolecules, proteins are formed from the linkage of monomers called **amino acids.** Hair and horns, as shown in Figure 3-7a, are made mostly of proteins, as are skin, muscles and many biological catalysts (enzymes).

Amino Acids

There are 20 different amino acids, and all share a basic structure. As Figure 3-7b shows, each amino acid contains a central carbon atom covalently bonded to four other atoms or functional groups. A single hydrogen atom, highlighted in blue in the illustration, bonds at one site. A carboxyl group, —COOH, highlighted in green, bonds at a second site. An amino group, $—NH_2$, highlighted in yellow, bonds at a third site. A side chain called the *R group,* highlighted in red, bonds at the fourth site.

The main difference among the different amino acids is in their R groups. The R group can be complex or it can be simple, such as the CH_3 group shown in the amino acid alanine in Figure 3-7b. The differences among the amino acid R groups gives different proteins very different shapes. The different shapes allow proteins to carry out many different activities in living things. Amino acids are commonly shown in a simplified way such as balls, as shown in Figure 3-7c.

Dipeptides and Polypeptides

Figure 3-8a shows how two amino acids bond to form a *dipeptide* (die-PEP-TIED). In this condensation reaction, the two amino acids form a covalent bond, called a **peptide bond** (shaded in blue in Figure 3-8a) and release a water molecule.

Amino acids often form very long chains called **polypeptides** (PAHL-i-PEP-TIEDZ). Proteins are composed of one or more polypeptides. Some proteins are very large molecules, containing hundreds of amino acids. Often, these long proteins are bent and folded upon themselves as a result of interactions—such as hydrogen bonding—between individual amino acids. Protein shape can also be influenced by conditions such as temperature and the type of solvent in which a protein is dissolved. For example, cooking an egg changes the shape of proteins in the egg white. The firm, opaque result is very different from the initial clear, runny material.

Enzymes

Enzymes—RNA or protein molecules that act as biological catalysts—are essential for the functioning of any cell. Many enzymes are proteins. Figure 3-9 shows an induced fit model of enzyme action.

Enzyme reactions depend on a physical fit between the enzyme molecule and its specific **substrate,** the reactant being catalyzed. Notice that the enzyme has folds, or an **active site,** with a shape that allows the substrate to fit into the active site. An enzyme acts only on a specific substrate because only that substrate fits into its active site. The linkage of the enzyme and substrate causes a slight change in the enzyme's shape. The change in the enzyme's shape weakens some chemical bonds in the substrate, which is one way that enzymes reduce activation energy, the energy needed to start the reaction. After the reaction, the enzyme releases the products. Like any catalyst, the enzyme itself is unchanged, so it can be used many times.

An enzyme may not work if its environment is changed. For example, change in temperature or pH can cause a change in the shape of the enzyme or the substrate. If such a change happens, the reaction that the enzyme would have catalyzed cannot occur.

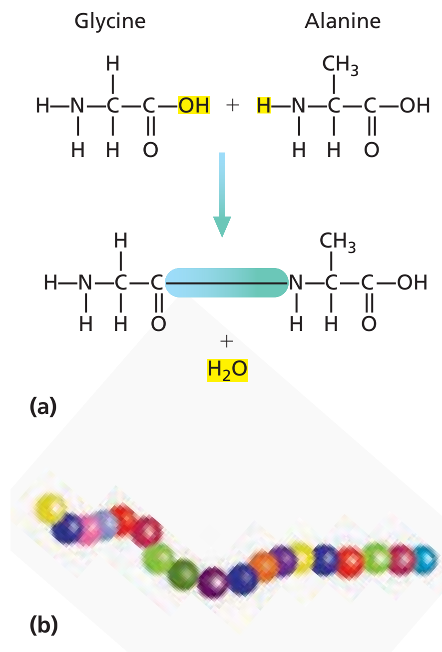


FIGURE 3-8

(a) The peptide bond (shaded blue) that binds amino acids together to form a polypeptide results from a condensation reaction that produces water. (b) Polypeptides are commonly shown as a string of balls in this textbook and elsewhere. Each ball represents an amino acid.

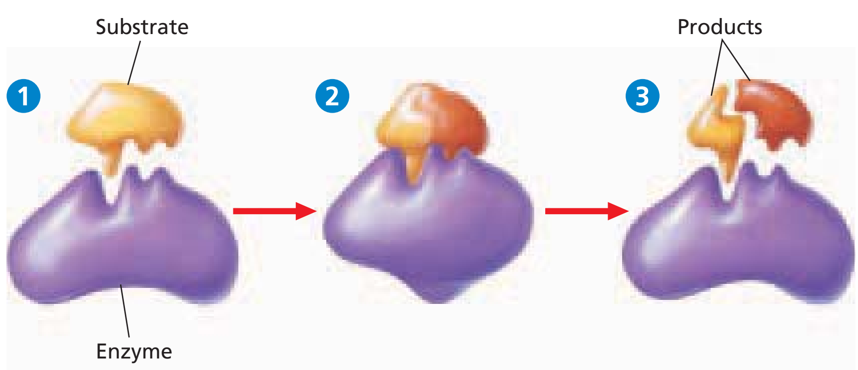
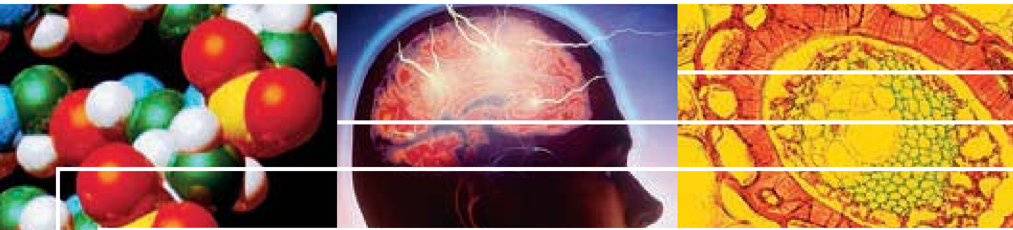


FIGURE 3-9

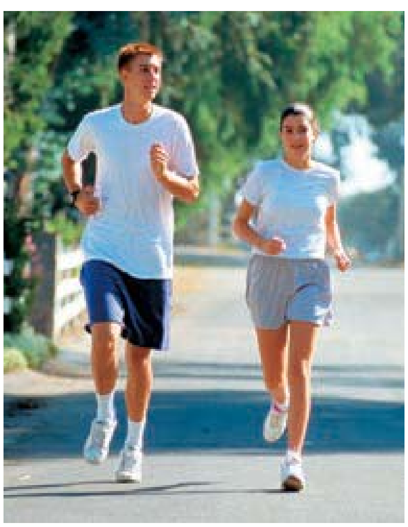
❶ In the induced fit model of enzyme action, the enzyme can attach only to a substrate (reactant) with a specific shape. ❷ The enzyme then changes and reduces the activation energy of the reaction so reactants can become products. ❸ The enzyme is unchanged and is available to be used again.



TREATING AND PREVENTING DIABETES

Proteins play many important roles in living organisms. The hormone *insulin* is a protein that stimulates cells to take up glucose. More than 18 million Americans have *diabetes,* an inability of the body to make or respond to insulin.

When the body cannot make or respond to insulin, the body's cells must switch to burning mainly fat as their fuel. The resulting high levels of fat in the blood can cause cardiovascular disease. In addition, the glucose that accumulates in the blood causes other problems. For example, diabetes can have serious complications, including kidney disease, heart failure, blindness, and amputation of the lower limbs. Some symptoms of diabetes include increased thirst, frequent urination, fatigue, and weight loss.



Regular physical activity can help reduce the risk of developing type 2 diabetes.

Type 1 Diabetes

Between 5 and 10 percent of people who suffer from diabetes have type 1 diabetes, which usually starts in childhood. The body's immune system mistakenly attacks cells in the pancreas that make insulin. If untreated, type 1 diabetes is usually fatal.

Treating Type 1 Diabetes

People with type 1 diabetes require a carefully monitored diet, physical activity, home blood glucose testing several times a day, and multiple daily insulin injections. In the past, insulin was delivered by shots. Now, there are pumps that regularly deliver small amounts of insulin. The pumps can be implanted surgically and refilled periodically by injection.

Type 2 Diabetes

The majority of people who suffer from diabetes have type 2 diabetes, which can begin at any age. A diet high in sugars and fats, a sedentary lifestyle, and being overweight can each increase the chances of developing this type of diabetes. Type 2 diabetes occurs when the pancreas cannot keep up with the demand for insulin or the cells become resistant to insulin's effects.

Treating Type 2 Diabetes

For type 2 diabetes, treatment typically includes a healthy diet, regular exercise, and home blood glucose testing. Some people must also take oral medication and/or insulin. About 40 percent of people with type 2 diabetes require insulin injections.

Preventing Diabetes

There is currently not a way to prevent type 1 diabetes. But exercise, a healthy diet, and insulin injections can allow a person to lead a normal life. Ways to prevent type 2 diabetes include exercising regularly and eating a healthy diet.

Future Treatments for Diabetes

Medical researchers are working on devices that can monitor blood sugar better. Other researchers are trying to improve the delivery of insulin by using timed-release drugs or by developing smaller implants. Some researchers are working on improving organ transplant surgery and finding genes linked to diabetes.

REVIEW

1. Distinguish between type 1 and type 2 diabetes.
2. Why is insulin important?
3. **Critical Thinking** A friend asks, "Why should I worry? By the time I'm old, they'll have diabetes cured anyway." What is your opinion? Defend your answer.

SCILINKS
www.scilinks.org
Topic: Diabetes
Keyword: HM60400

LIPIDS

Lipids are large, nonpolar organic molecules. They do not dissolve in water. Lipids include **triglycerides** (trie-GLIS-uhr-IEDZ), phospholipids, steroids, waxes, and pigments. Lipid molecules have a higher ratio of carbon and hydrogen atoms to oxygen atoms than carbohydrates have. Because lipid molecules have larger numbers of carbon-hydrogen bonds per gram than other organic compounds do, they store more energy per gram.

Fatty Acids

Fatty acids are unbranched carbon chains that make up most lipids. Figure 3-10 shows that a fatty acid contains a long carbon chain (from 12 to 28 carbons) with a carboxyl group, —COOH, attached at one end. The two ends of the fatty-acid molecule have different properties. The carboxyl end is polar and is thus *hydrophilic* or attracted to water molecules. In contrast, the hydrocarbon end of the fatty-acid molecule is nonpolar. This end tends not to interact with water molecules and is said to be *hydrophobic* (HIE-droh-FOH-bik), or "water fearing."

In saturated fatty acids, such as palmitic acid, which is shown in Figure 3-10, each carbon atom is covalently bonded to four atoms. The carbon atoms are in effect full, or *saturated*. In contrast, linoleic acid, also shown in Figure 3-10, has carbon atoms that are not bonded to the maximum number of atoms to which they can bond. Instead, they have formed double bonds within the carbon chain. This type of fatty acid is said to be *unsaturated*.

Triglycerides

Three classes of lipids important to living things contain fatty acids: triglycerides (fats), phospholipids, and waxes. A *triglyceride* is composed of three molecules of fatty acid joined to one molecule of the alcohol glycerol. Saturated triglycerides are composed of saturated fatty acids. They typically have high melting points and tend to be hard at room temperature. Common dietary saturated triglycerides include butter and fats in red meat. In contrast, unsaturated triglycerides are composed of unsaturated fatty acids and are usually soft or liquid at room temperature. Unsaturated triglycerides are found primarily in plant seeds where they serve as an energy and carbon source for germinating plants.

Phospholipids

Phospholipids have two, rather than three, fatty acids attached to a molecule of glycerol. They have a phosphate group attached to the third carbon of the glycerol. As shown in Figure 3-11, the cell membrane is made of two layers of phospholipids, called the *lipid bilayer*. The inability of lipids to dissolve in water allows the membrane to form a barrier between the inside and outside of the cell.

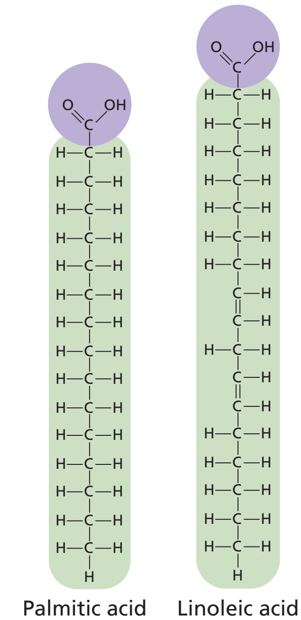
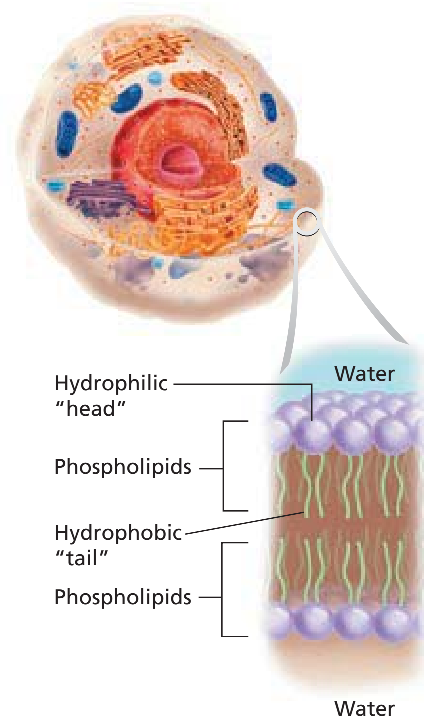


FIGURE 3-10
Fatty acids have a polar carboxyl head, highlighted in purple, and a nonpolar hydrocarbon tail, highlighted in green.

FIGURE 3-11
The lipid bilayer of a cell membrane is a double row of phospholipids. The "tails" face each other. The "head" of a phospholipid, which contains a phosphate group, is polar and hydrophilic. The two tails are two fatty acids and are nonpolar and hydrophobic.



SCILINKS.

www.scilinks.org
Topic: Lipids
Keyword: HM60188

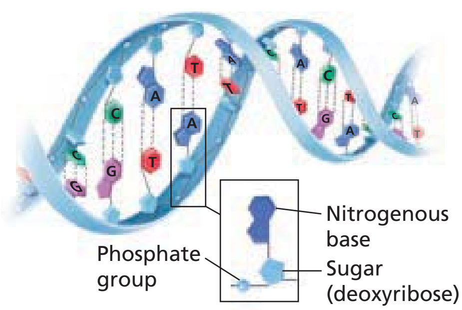
Waxes

A **wax** is a type of structural lipid consisting of a long fatty-acid chain joined to a long alcohol chain. Waxes are waterproof, and in plants, form a protective coating on the outer surfaces. Waxes also form protective layers in animals. For example, earwax helps prevent microorganisms from entering the ear canal.

Steroids

Unlike most other lipids, which are composed of fatty acids, **steroid** molecules are composed of four fused carbon rings with various functional groups attached to them. Many animal hormones, such as the male hormone testosterone, are steroid compounds. One of the most familiar steroids in humans is cholesterol. Cholesterol is needed by the body for nerve and other cells to function normally. It is also a component of the cell membrane.

FIGURE 3-12
DNA as shown below, and RNA, are very large molecules formed from nucleotides linked together in a chain. A nucleotide consists of a phosphate group, a five-carbon sugar, and a ring-shaped nitrogenous base.



NUCLEIC ACIDS

Nucleic acids are very large and complex organic molecules that store and transfer important information in the cell. There are two major types of nucleic acids: deoxyribonucleic acid and ribonucleic acid.

Deoxyribonucleic acid, or **DNA,** contains information that determines the characteristics of an organism and directs its cell activities. **Ribonucleic** (RIE-boh-noo-KLEE-ik) **acid,** or **RNA,** stores and transfers information from DNA that is essential for the manufacturing of proteins. Some RNA molecules can also act as enzymes. Both DNA and RNA are polymers, composed of thousands of linked monomers called *nucleotides* (NOO-klee-uh-TIEDS). As shown in Figure 3-12, each **nucleotide** is made of three main components: a phosphate group, a five-carbon sugar, and a ring-shaped nitrogenous base.

SECTION 2 REVIEW

1. Compare the structure of monosaccharides, disaccharides, and polysaccharides.
2. How are proteins constructed from amino acids?
3. How do amino acids differ from one another?
4. Describe a model of enzyme action.
5. Why do phospholipids orient in a bilayer when in a watery environment, such as a cell?
6. Describe how the three major types of lipids differ in structure from one another.
7. What are the functions of the two types of nucleic acids?

CRITICAL THINKING

8. **Applying Information** Before a long race, runners often "carbo load." This means that they eat substantial quantities of carbohydrates. How might this help their performance?
9. **Recognizing Relationships** High temperatures can weaken bonds within a protein molecule. How might this explain the effects of using a hot curling iron or rollers in one's hair?
10. **Applying Information** You want to eat more unsaturated than saturated fats. Name examples of foods you would eat more of and less of.

CHAPTER HIGHLIGHTS

SECTION 1 Carbon Compounds

- Organic compounds contain carbon atoms and are found in living things. Most inorganic compounds do not contain carbon atoms.
- Carbon atoms can readily form four covalent bonds with other atoms including other carbon atoms. The carbon bonds allow the carbon atoms to form a wide variety of simple and complex organic compounds.
- Functional groups are groups of atoms that influence the properties of molecules and the chemical reactions in which the molecules participate.
- Condensation reactions join monomers (small simple molecules) to form polymers. A condensation reaction releases water as a by-product. In a hydrolysis reaction, water is used to split polymers into monomers.
- Adenosine triphosphate (ATP) stores and releases energy during cell processes enabling organisms to function.

Vocabulary

organic compound (p. 51)
functional group (p. 52)
monomer (p. 53)
polymer (p. 53)
macromolecule (p. 53)
condensation reaction (p. 53)
hydrolysis (p. 53)
adenosine triphosphate (ATP) (p. 54)

SECTION 2 Molecules of Life

- There are four main classes of organic compounds: carbohydrates, proteins, lipids, and nucleic acids.
- Carbohydrates are made up of monomers called monosaccharides. Two monosaccharides join to form a double sugar called a disaccharide. A complex sugar, or polysaccharide, is made of three or more monosaccharides.
- Carbohydrates such as glucose, are a source of energy and are used as structural materials in organisms.
- Proteins have many functions including structural, defensive, and catalytic. Proteins are made up of monomers called amino acids. The sequence of amino acids determines a protein's shape and function. A long chain of amino acids is called a polypeptide, which is made up of amino acids joined by peptide bonds.
- Enzymes speed up chemical reactions and bind to specific substrates. The binding of a substrate with an enzyme causes a change in the enzyme's shape and reduces the activation energy of the reaction.
- Lipids are nonpolar molecules that store energy and are an important part of cell membranes. Most lipids contain fatty acids, molecules that have a hydrophilic end and a hydrophobic end.
- There are three kinds of lipids: Triglycerides consist of three fatty acids and one molecule of glycerol. Phospholipids, which make up cell membranes, consist of two fatty acids and one glycerol molecule. A wax is made of one long fatty acid chain joined to one long alcohol.
- The nucleic acid, deoxyribonucleic acid (DNA), contains all the genetic information for cell activities. Ribonucleic acid (RNA) molecules play many key roles in building of proteins and can act as enzymes.

Vocabulary

carbohydrate (p. 55)
monosaccharide (p. 55)
disaccharide (p. 56)
polysaccharide (p. 56)
protein (p. 56)
amino acid (p. 56)
peptide bond (p. 57)
polypeptide (p. 57)
enzyme (p. 57)
substrate (p. 57)
active site (p. 57)
lipid (p. 59)
fatty acid (p. 59)
triglyceride (p. 59)
phospholipid (p. 59)
wax (p. 60)
steroid (p. 60)
nucleic acid (p. 60)
deoxyribonucleic acid (DNA) (p. 60)
ribonucleic acid (RNA) (p. 60)
nucleotide (p. 60)

CHAPTER REVIEW

USING VOCABULARY

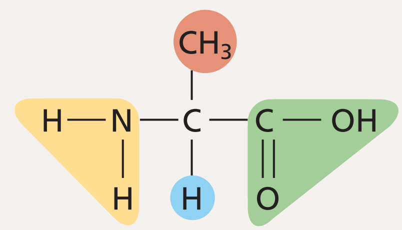
1. For each pair of terms, explain how the meanings of the terms differ.
   a. *monomer* and *polymer*
   b. *functional group* and *macromolecule*
   c. *monosaccharide* and *disaccharide*
   d. *polypeptide* and *protein*
   e. *nucleic acid* and *nucleotide*
2. For each pair of terms, explain the relationship between the terms.
   a. *fatty acid* and *triglyceride*
   b. *substrate* and *enzyme*
3. Use the following terms in the same sentence: *monomer, polymer, condensation reaction,* and *hydrolysis*.
4. **Word Roots and Origins** The word *organic* is derived from the Greek *organikos,* which means "organ." Explain how the word *organic* is descriptive of most carbon compounds.

UNDERSTANDING KEY CONCEPTS

5. **Differentiate** between organic and inorganic compounds.
6. **Relate** the properties of carbon to the formation of organic compounds.
7. **Summarize** how functional groups help determine the properties of organic compounds.
8. **Compare** how organic compounds are built to how they are broken down.
9. **Explain** the role of ATP in cellular activities.
10. **List** the four major classes of organic compounds.
11. **Describe** the general structure of carbohydrates.
12. **Define** the term *isomer*.
13. **Summarize** the differences between simple sugars, double sugars, and complex sugars.
14. **Describe** how a protein's structure is determined by the arrangement of amino acids.
15. **State** the basic structure of an amino acid.
16. **Compare** the processes used in the formation of a dipeptide and a disaccharide.
17. **Summarize** the induced fit model of enzyme activity.
18. **Differentiate** between saturated and unsaturated triglycerides.
19. **Compare** the structures of triglycerides, phospholipids, and steroids.
20. **State** how steroids differ from other lipids.
21. **Identify** an important characteristic of waxes in living organisms.
22. **Compare** two kinds of nucleic acids.
23. **Name** the three parts of a nucleotide.
24. **CONCEPT MAPPING** Use the following terms to create a concept map that describes the different types of organic compounds: *dipeptide, triglycerides, RNA, phospholipids, carbohydrates, monosaccharide, amino acid, disaccharide, polypeptide, polysaccharide, proteins, DNA, lipids, nucleic acids, steroids,* and *waxes*.

CRITICAL THINKING

25. **Applying Information** What is the chemical formula for a monosaccharide that has three carbons?
26. **Analyzing Concepts** Starch easily dissolves in water. Cellulose does not. Both substances, however, consist of chains of glucose molecules. What structural difference between starch and cellulose might account for their different behavior in water?
27. **Interpreting Graphics** Identify the type of organic molecule shown below. Identify each of the functional groups shaded in yellow, red, and green.



28. **Making Inferences** Analysis of an unknown substance showed that it has the following characteristics: It contains carbon, hydrogen, and oxygen and it is soluble in oil but not water. Predict what kind of substance it might be. Explain your answer.
29. **Applying Information** Many birds store significant amounts of energy to power flight during winter migration. What type of organic molecule might be best suited for energy storage? Explain.

Standardized Test Preparation

DIRECTIONS: Choose the letter of the answer choice that best answers the question.

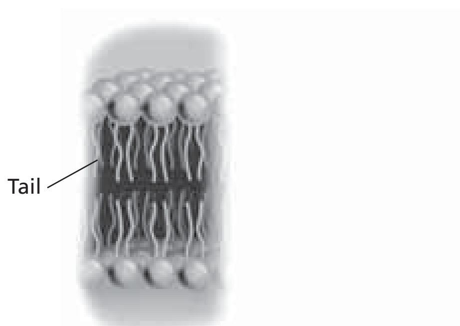
1. Which of the following is not a function of polysaccharides?
   A. energy source
   B. energy storage
   C. structural support
   D. storage of genetic information

2. Which of the following statements is false?
   F. A wax is a lipid.
   G. Starch is a lipid.
   H. Saturated fats are solid at room temperature.
   J. Unsaturated fats are liquid at room temperature.

3. Which of the following molecules stores hereditary information?
   A. ATP
   B. DNA
   C. protein
   D. carbohydrates

4. What is the name of the molecule in plants that stores sugars?
   F. starch
   G. protein
   H. cellulose
   J. glycogen

INTERPRETING GRAPHICS: The figure below illustrates the basic structure of a cell membrane. Use the figure to answer the questions that follow.



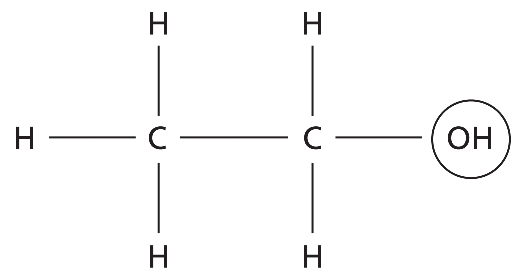
5. Which of the following molecules make up the basic structure of a cell membrane?
   A. waxes
   B. steroids
   C. fatty acids
   D. phospholipids

6. The "tails" of the molecules in the figure orient away from water. Which of the following describes the tail's movement away from water?
   F. polar
   G. adhesive
   H. hydrophilic
   J. hydrophobic

DIRECTIONS: Complete the following analogy.

7. simple sugars : carbohydrates :: amino acids :
   A. lipids
   B. proteins
   C. nucleic acids
   D. amino groups

INTERPRETING GRAPHICS: The figure below represents the structural formula of a molecule. Use the figure to answer the question that follows.



8. What is the name of the functional group circled in the structural formula above?
   F. amino
   G. hydroxyl
   H. phosphate
   J. carboxyl

SHORT RESPONSE

Proteins are affected by environmental conditions such as heat and pH.

Explain why the process of cooking an egg cannot be reversed.

EXTENDED RESPONSE

Enzymes are essential for the functioning of all cells.

Part A Explain what enzymes do that is essential for cell function.

Part B Explain the induced fit model of enzyme action.

Test TIP When writing an answer to an extended response question, make an outline of what you plan to write before writing your answer. Although it may take a little more time, the answer will be easier to write.

INQUIRY LAB

Identifying Organic Compounds in Foods

OBJECTIVES

- Determine whether specific nutrients are present in a solution of unknown composition.
- Perform chemical tests using substances called *indicators.*

MATERIALS

- lab apron
- safety goggles
- protective gloves
- 500 mL beaker
- hot plate
- 9 test tubes
- labeling tape
- marker
- 10 mL graduated cylinder
- Benedict's solution
- 9 dropping pipets
- glucose solution
- unknown solution
- distilled water
- 9 glass stirring rods
- tongs or test-tube holder
- test-tube rack
- albumin solution
- sodium hydroxide solution
- copper sulfate solution
- vegetable oil
- Sudan III solution

SAFETY

Background

1. Carbohydrates, proteins, and lipids are nutrients that make up all living things. Some foods, such as table sugar, contain only one of these nutrients. Most foods, however, contain mixtures of proteins, carbohydrates, and lipids. You can confirm this fact by reading the information in the Nutrition Facts box found on any food label.
2. In this investigation, you will use chemical substances, called *indicators,* to identify the presence of specific nutrients in an unknown solution. By comparing the color change an indicator produces in the unknown food sample with the change it produces in a sample of known composition, you can determine whether specific organic compounds are present in the unknown sample.
3. Benedict's solution is used to determine the presence of monosaccharides, such as glucose. A mixture of sodium hydroxide and copper sulfate indicates the presence of some proteins. This procedure is called the biuret test. Sudan III is used to indicate the presence of lipids.

Procedure

CAUTION **Put on a lab apron, safety goggles, and gloves. In this lab, you will be working with chemicals that can harm your skin and eyes or stain your skin and clothing. If you get a chemical on your skin or clothing, wash it off at the sink while calling to your teacher. If you get a chemical in your eyes, immediately flush it out at the eyewash station while calling to your teacher.** As you perform each test, record your data in your lab report, organized in a table such as the one on the next page.

Test 1: Monosaccharides

1. CAUTION **Do not touch the hot plate. Use tongs to move heated objects. Turn off the hot plate when not in use. Do not plug in or unplug the hot plate with wet hands.** Make a water bath by filling a 500 mL beaker half full with water. Then, put the beaker on a hot plate, and bring the water to a boil.
2. While you wait for the water to boil, label one test tube "1-glucose," label the second test tube "1-unknown," and label the third test tube "1-water." Using the graduated cylinder, measure 5 mL of Benedict's solution, and add it to the "1-glucose" test tube. Repeat the procedure, adding 5 mL of Benedict's solution each to the "1-unknown" test tube and "1-water" test tube.
3. Using a dropping pipet or eyedropper, add 10 drops of glucose solution to the "1-glucose" test tube. Using a second dropping pipet, add 10 drops of the unknown solution to the "1-unknown" test tube.

IDENTIFICATION OF SPECIFIC NUTRIENTS BY CHEMICAL INDICATORS

Test	Nutrient in test solution	Nutrient category (protein, lipid, etc.)	Result for known sample	Result for unknown sample	Result for distilled water
1					
2					
3					

Using a third dropping pipet, add 10 drops of distilled water to the "1-water" test tube. Mix the contents of each test tube with a clean stirring rod. **(It is important not to contaminate test solutions by using the same dropping pipet or stirring rod in more than one solution. Use a different dropping pipet and stirring rod for each of the test solutions.)**

4. When the water boils, use tongs to place the test tubes in the water bath. Boil the test tubes for 1 to 2 minutes.
5. CAUTION **Do not touch the test tubes with your hands. They will be very hot.** Use tongs to remove the test tubes from the water bath and place them in the test-tube rack. As the test tubes cool, an orange or red precipitate will form if large amounts of glucose are present. If small amounts of glucose are present, a yellow or green precipitate will form. Record your results in your data table.

Test 2: Proteins

6. Label one clean test tube "2-albumin," label a second test tube "2-unknown," and label a third test tube "2-water." Using a dropping pipet, add 40 drops of albumin solution to the "2-albumin" test tube. Using a second dropping pipet, add 40 drops of unknown solution to the "2-unknown" test tube. Using a third dropping pipet, add 40 drops of water to the "2-water" test tube.
7. Add 40 drops of sodium hydroxide solution to each of the three test tubes. Mix the contents of each test tube with a clean stirring rod.
8. Add a few drops of copper sulfate solution, one drop at a time, to the "2-albumin" test tube. Stir the solution with a clean stirring rod after each drop. Note the number of drops required to cause the color of the solution in the test tube to change. Then, add the same number of drops of copper sulfate solution to the "2-unknown" and "2-water" test tubes.
9. Record your results in your data table.

Test 3: Lipids

10. Label one clean test tube "3-vegetable oil," label a second test tube "3-unknown," and label a third test tube "3-water." Using a dropping pipet, add 5 drops of vegetable oil to the "3-vegetable oil" test tube. Using a second dropping pipet, add 5 drops of the unknown solution to the "3-unknown" test tube. Using a third dropping pipet, add 5 drops of water to the "3-water" test tube.
11. CAUTION **Sudan III solution will stain your skin and clothing. Promptly wash off spills to minimize staining. Do not use Sudan III solution in the same room with an open flame.** Using a clean dropping pipet, add 3 drops of Sudan III solution to each test tube. Mix the contents of each test tube with a clean stirring rod.
12. Record you results in your data table.
13. Clean up your materials, and wash your hands before leaving the lab.

Analysis and Conclusions

1. Based on the results you recorded in your data table, identify the nutrient or nutrients in the unknown solution.
2. What are the experimental controls in this investigation?
3. Explain how you were able to use the color changes of different indicators to determine the presence of specific nutrients in the unknown substance.
4. List four potential sources of error in this investigation.

Further Inquiry

Is there a kind of macromolecule that the tests in this lab did not test for? If so, list the kinds of macromolecules not tested for, and give one reason why they were not tested for.

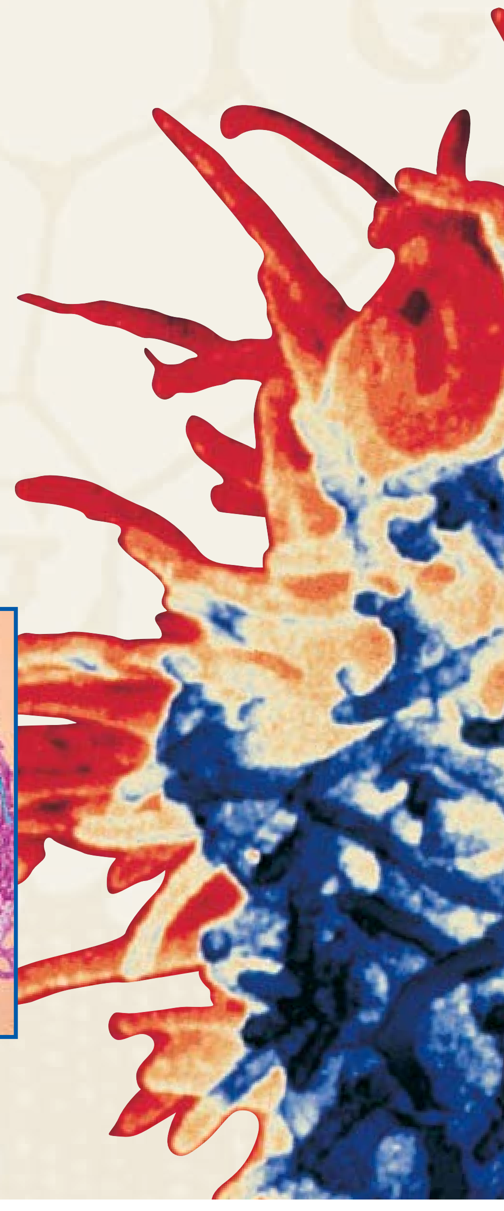
UNIT

2

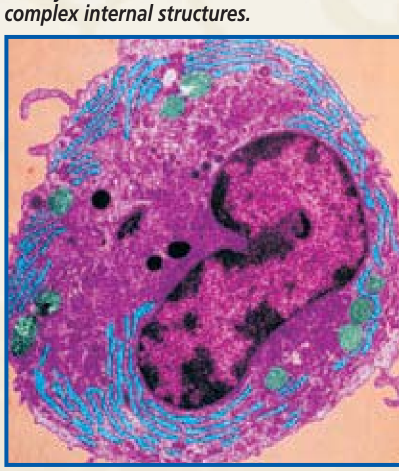
CHAPTERS

CELL BIOLOGY

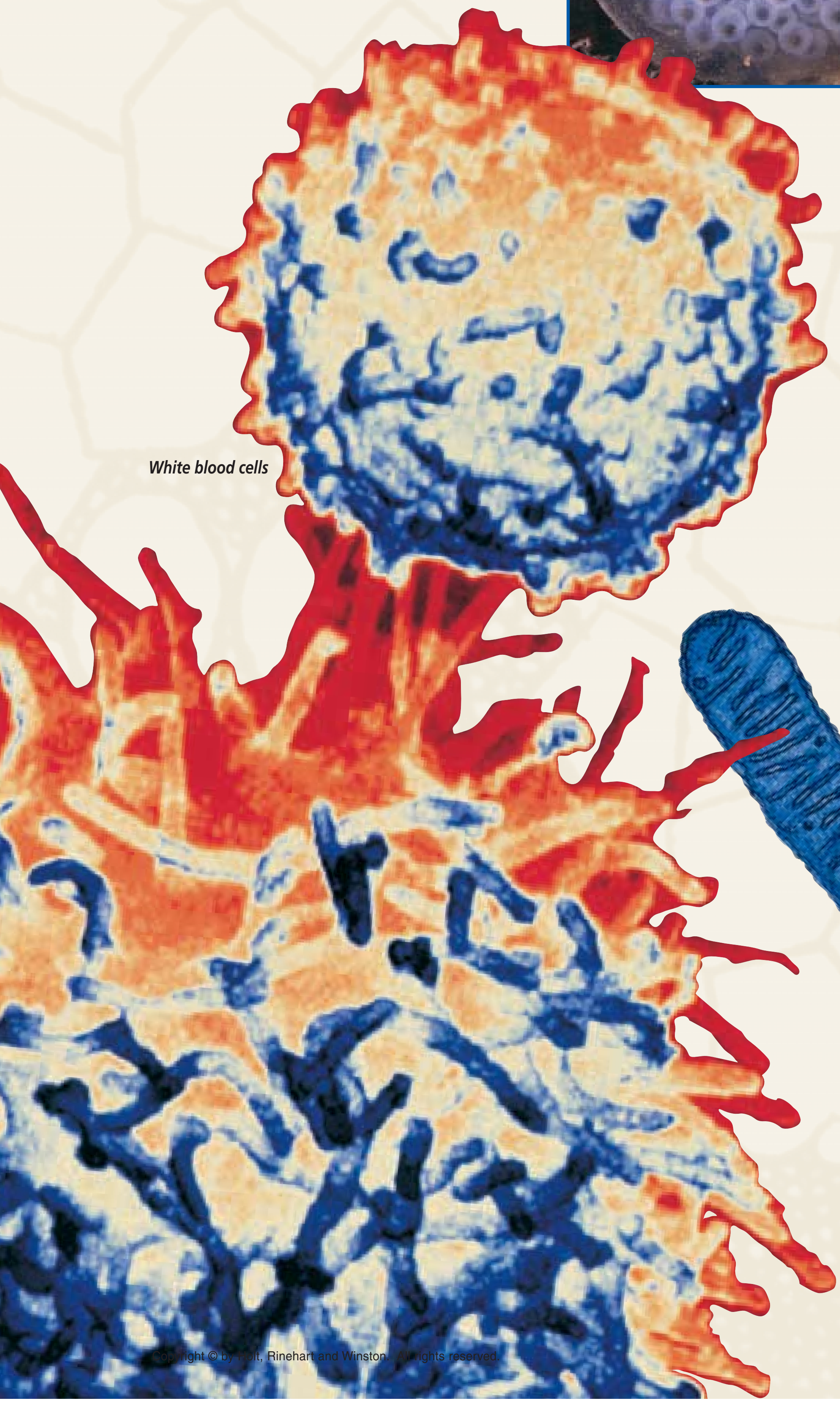
"The cell is the natural granule of life in the same way as the atom is the natural granule of simple, elemental matter. If we are to take the measure of the transit to life and determine its precise nature, we must try to understand the cell."



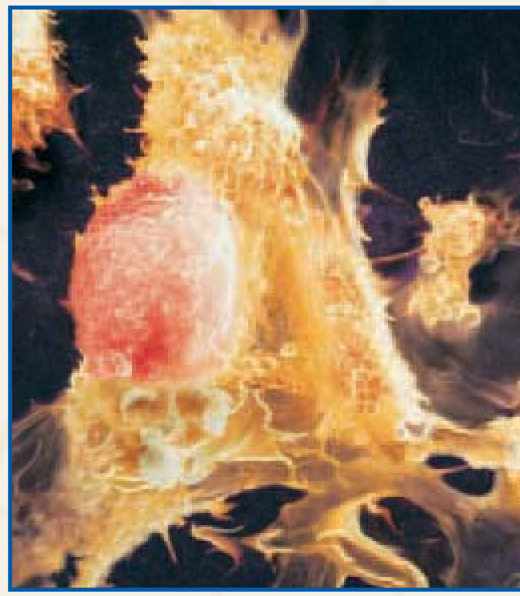
Eukaryotic cells contain a number of complex internal structures.



Most cells are very small, but these frog eggs can be seen with the unaided eye.



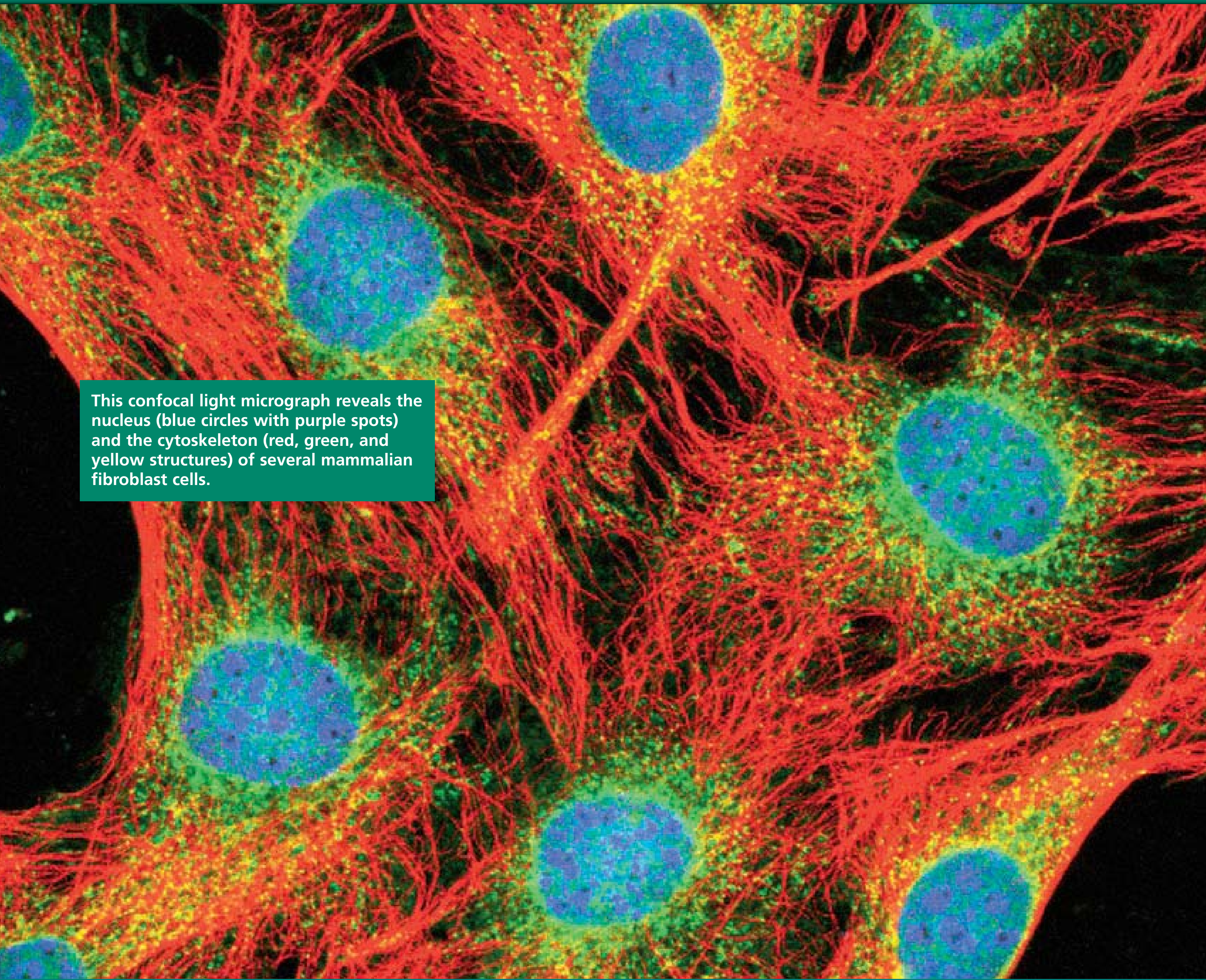
White blood cells



The orange-stained immune system cell shown above is attacking and ingesting the red-stained tumor cell. Mitochondria (below left) provide cells with the energy necessary for life.

CHAPTER 4

CELL STRUCTURE AND FUNCTION



This confocal light micrograph reveals the nucleus (blue circles with purple spots) and the cytoskeleton (red, green, and yellow structures) of several mammalian fibroblast cells.

Biology Virtual Investigations
Virtual Tour of an Animal Cell

SECTION 1

THE HISTORY OF CELL BIOLOGY

Both living and nonliving things are made of atoms, molecules, and compounds. How are living and nonliving things different? The discovery of the cell was an important step toward answering this question.

OBJECTIVES

- **Name** the scientists who first observed living and nonliving cells.
- **Summarize** the research that led to the development of the cell theory.
- **State** the three principles of the cell theory.
- **Explain** why the cell is considered to be the basic unit of life.

VOCABULARY

cell
cell theory

THE DISCOVERY OF CELLS

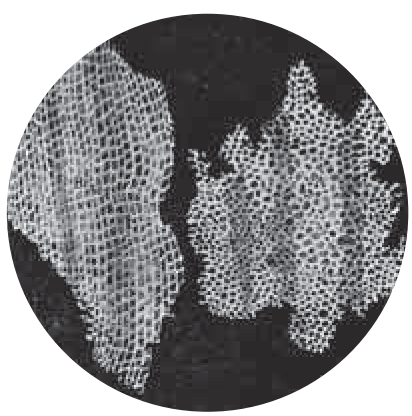
All living things are made up of one or more cells. A **cell** is the smallest unit that can carry on all of the processes of life. Beginning in the 17th century, curious naturalists were able to use microscopes to study objects too small to be seen with the unaided eye. Their studies led them to propose the cellular basis of life.

Hooke

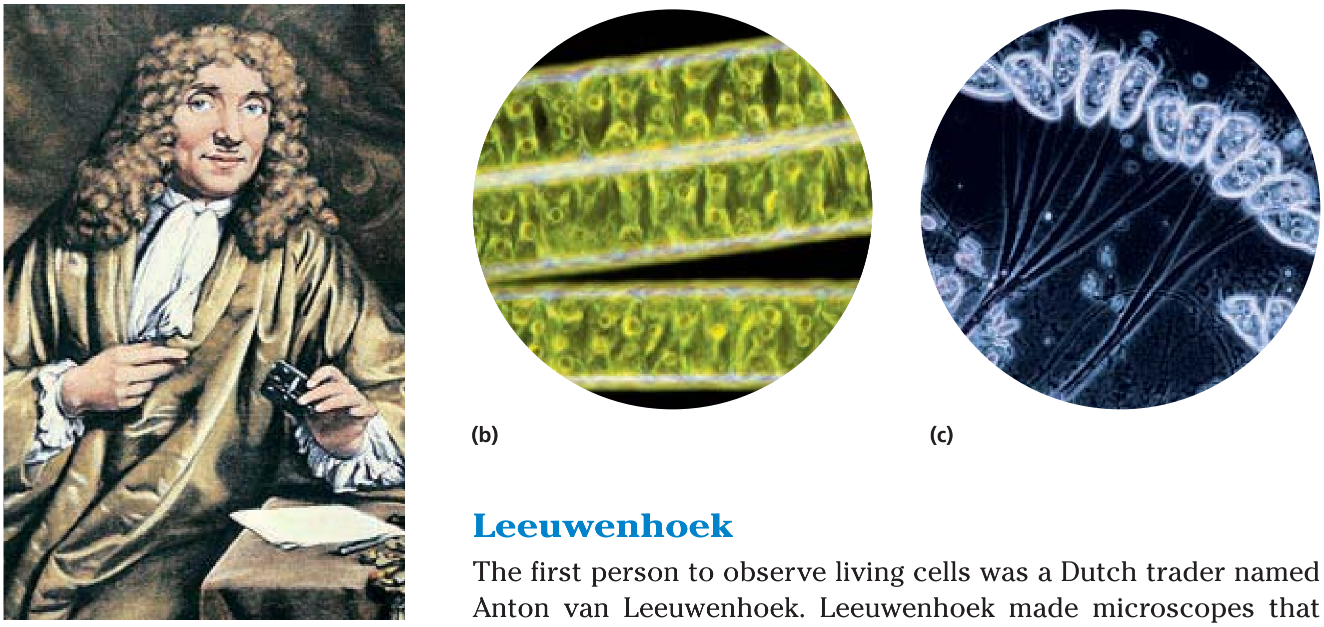
In 1665, English scientist Robert Hooke studied nature by using an early *light microscope,* such as the one in Figure 4-1a. A light microscope is an instrument that uses optical lenses to magnify objects by bending light rays. Hooke looked at a thin slice of cork from the bark of a cork oak tree. "I could exceedingly plainly perceive it to be all perforated and porous," Hooke wrote. He described "a great many little boxes" that reminded him of the cubicles or "cells" where monks live. When Hooke focused his microscope on the cells of tree stems, roots, and ferns, he found that each had similar little boxes. The drawings that Hooke made of the cells he saw are shown in Figure 4-1b. The "little boxes" that Hooke observed were the remains of dead plant cells, such as the cork cells shown in Figure 4-1c.

FIGURE 4-1
Robert Hooke used an early microscope (a) to see cells in thin slices of cork. His drawings of what he saw (b) indicate that he had clearly observed the remains of cork cells (300×) (c).


(a)


(b)


(c)



(a)

(b)

(c)

FIGURE 4-2

Anton van Leeuwenhoek (1632–1723) is shown here with one of his hand-held lenses (a). Leeuwenhoek observed an alga of the genus *Spirogyra* (b) and a protist of the genus *Vorticella* (c).

Leeuwenhoek

The first person to observe living cells was a Dutch trader named Anton van Leeuwenhoek. Leeuwenhoek made microscopes that were simple and tiny, but he ground lenses so precisely that the magnification was 10 times that of Hooke's instruments. In 1673, Leeuwenhoek, shown in Figure 4-2a, was able to observe a previously unseen world of microorganisms. He observed cells with green stripes from an alga of the genus *Spirogyra,* as shown in Figure 4-2b, and bell-shaped cells on stalks of a protist of the genus *Vorticella,* as shown in Figure 4-2c. Leeuwenhoek called these organisms *animalcules.* We now call them *protists.*

THE CELL THEORY

Although Hooke and Leeuwenhoek were the first to report observing cells, the importance of this observation was not realized until about 150 years later. At this time, biologists began to organize information about cells into a unified understanding. In 1838, the German botanist Matthias Schleiden concluded that all plants were composed of cells. The next year, the German zoologist Theodor Schwann concluded the same thing for animals. And finally, in his study of human diseases, the German physician Rudolf Virchow (1821–1902) noted that all cells come from other cells. These three observations were combined to form a basic theory about the cellular nature of life. The **cell theory** has three essential parts, which are summarized in Table 4-1.

SCILINKS.

www.scilinks.org
Topic: Cell Theory
Keyword: HM60241

TABLE 4-1 ***The Cell Theory***

All living organisms are composed of one or more cells.
Cells are the basic units of structure and function in an organism.
Cells come only from the reproduction of existing cells.

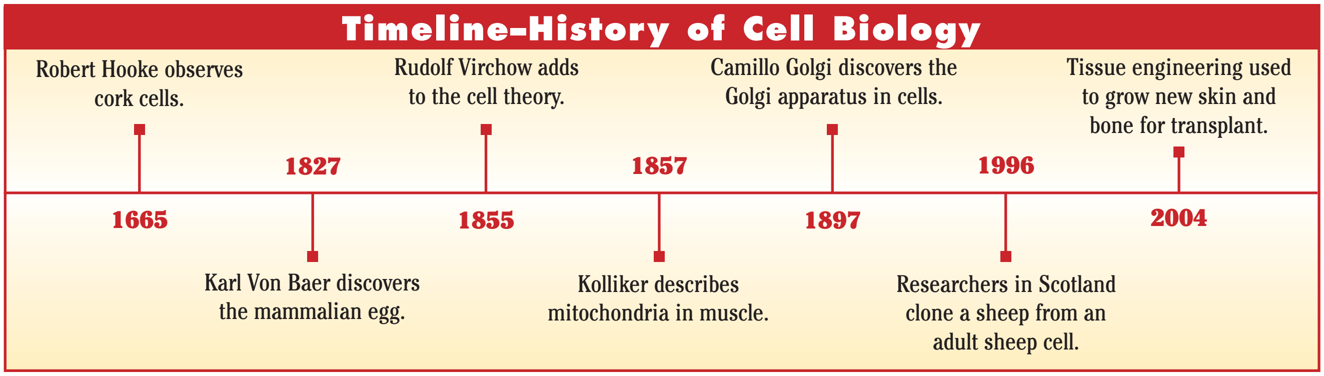


FIGURE 4-3
The study of cell biology began with the discovery of the cell by Robert Hooke in 1665. Since then, constantly improving technology has allowed scientists to unlock the secrets of the cell.

Developments in Cell Biology

The discovery of cells and the development of the cell theory happened at the beginning of a revolutionary time in the history of science. Before the invention of the microscope, many questions about what makes up living and nonliving things could not be answered. Once cells could be observed, these questions could be explored. Scientists could then turn their attention to finding out how cells function. Figure 4-3 lists some of the major events in the history of cell biology.

The Cellular Basis of Life

Microscopes helped biologists clarify our definition of life. All living things share several basic characteristics. All living things consist of organized parts, obtain energy from their surroundings, perform chemical reactions, change with time, respond to their environments, and reproduce.

In addition, living things must be able to separate their relatively constant internal environment from the ever-changing external environment. The ability to maintain a constant internal environment, called *homeostasis,* will be discussed later. Finally, all living things share a common history. All cells share characteristics that indicate that cells are related to other living things.

SECTION 1 REVIEW

1. Describe the major contributions of Hooke and Leeuwenhoek to cell biology.
2. Identify the advance that enabled Leeuwenhoek to view the first living cells.
3. Describe the research that led to the development of the cell theory.
4. State the three fundamental parts of the cell theory.
5. List three major events in the history of cell biology.
6. Name eight characteristics that all living things share.

CRITICAL THINKING

7. **Applying Concepts** If you could go back in time, how would you explain the cell theory to someone who had never heard of cells?
8. **Making Calculations** A biologist photographs a cell in a microscope magnified at 40 times. The cell in the photo is 2 mm in diameter. What is the true diameter of the cell in micrometers (μm)?
9. **Justifying Conclusions** If organisms exist on other planets, would they consist of cells? Defend your answer.

SECTION 2

OBJECTIVES

- **Explain** the relationship between cell shape and cell function.
- **Identify** the factor that limits cell size.
- **Describe** the three basic parts of a cell.
- **Compare** prokaryotic cells and eukaryotic cells.
- **Analyze** the relationship among cells, tissues, organs, organ systems, and organisms.

VOCABULARY

plasma membrane
cytoplasm
cytosol
nucleus
prokaryote
eukaryote
organelle
tissue
organ
organ system

INTRODUCTION TO CELLS

Cells come in a variety of shapes and sizes that suit their diverse functions. There are at least 200 types of cells, ranging from flat cells to branching cells to round cells to rectangular cells.

CELL DIVERSITY

Cells of different organisms and even cells within the same organism are very diverse in terms of shape, size, and internal organization. One theme that occurs again and again throughout biology is that form follows function. In other words, a cell's function influences its physical features.

Cell Shape

The diversity in cell shapes reflects the different functions of cells. Compare the cell shapes shown in Figure 4-4. The long extensions that reach out in various directions from the nerve cell shown in Figure 4-4a allow the cell to send and receive nerve impulses. The flat, platelike shape of skin cells in Figure 4-4b suits their function of covering and protecting the surface of the body. As shown below, a cell's shape can be simple or complex depending on the function of the cell. Each cell has a shape that has evolved to allow the cell to perform its function effectively.

FIGURE 4-4

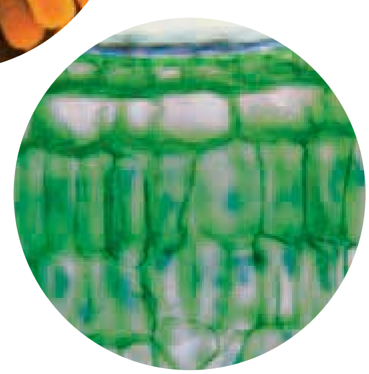
Cells have various shapes. (a) Nerve cells have long extensions. (b) Skin cells are flat and platelike. (c) Egg cells are spherical. (d) Some bacteria are rod shaped. (e) Some plant cells are rectangular.

(b) Skin cells

(d) Bacterial cells

(a) Nerve cell

(c) Egg cell



(e) Plant cells

Cell Size

Cells differ not only in their shape but also in their size. A few types of cells are large enough to be seen by the unaided human eye. For example, the nerve cells that extend from a giraffe's spinal cord to its foot can be 2 m (about 6 1/2 ft) long. A human egg cell is about the size of the period at the end of this sentence. Most cells, however, are only 10 to 50 µm in diameter, or about 1/500 the size of the period at the end of this sentence.

The size of a cell is limited by the relationship of the cell's outer surface area to its volume, or its *surface area–to-volume ratio.* As a cell grows, its volume increases much faster than its surface area does, as shown in Figure 4-5. This trend is important because the materials needed by a cell (such as nutrients and oxygen) and the wastes produced by a cell (such as carbon dioxide) must pass into and out of the cell through its surface. If a cell were to become very large, the volume would increase much more than the surface area. Therefore, the surface area would not allow materials to enter or leave the cell quickly enough to meet the cell's needs. As a result, most cells are microscopic in size.

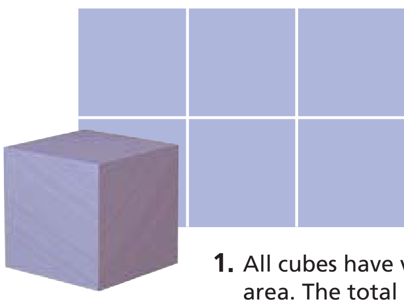
Quick Lab

Comparing Surface Cells

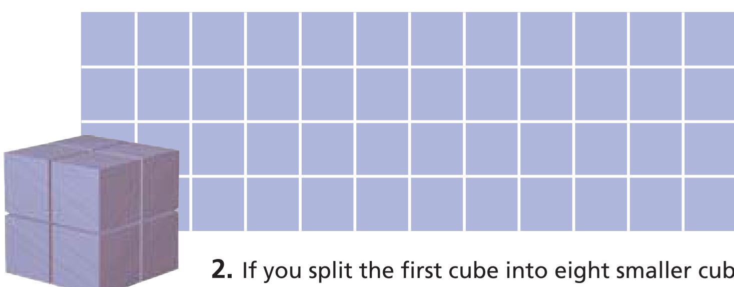
Materials microscope, prepared slides of plant (dicot) stem and animal (human) skin, pencil, paper

Procedure Examine slides by using medium magnification (100×). Observe and draw the surface cells of the plant stem and the animal skin.

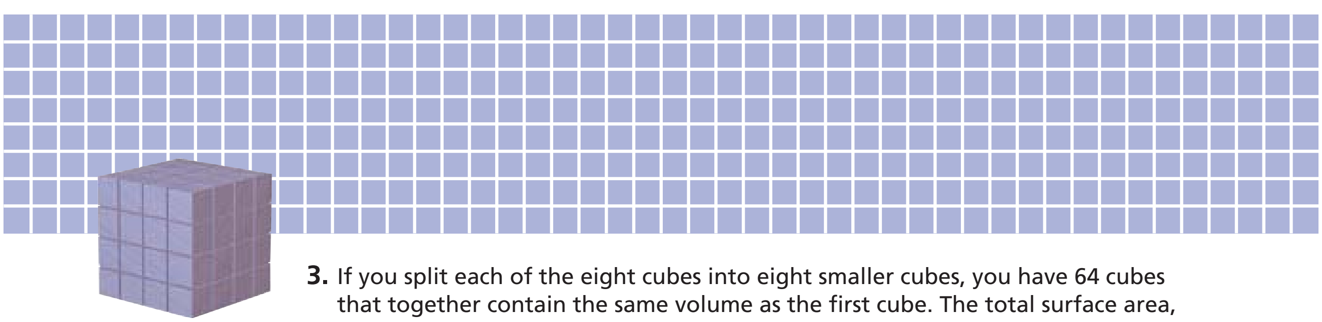
Analysis How do the surface cells of each organism differ from the cells beneath the surface cells? What is the function of the surface cells? Explain how surface cells are suited to their function based on their shape.



1. All cubes have volume and surface area. The total surface area is equal to the sum of the areas of each of the six sides (area = length X width).



2. If you split the first cube into eight smaller cubes, you get 48 sides. The volume remains constant, but the total surface area doubles.



3. If you split each of the eight cubes into eight smaller cubes, you have 64 cubes that together contain the same volume as the first cube. The total surface area, however, has doubled again.

FIGURE 4-5

Small cells can exchange substances more readily than large cells because small objects have a higher surface area–to-volume ratio.

BASIC PARTS OF A CELL

Despite the diversity among cells, three basic features are common to all cell types. All cells have an outer boundary, an interior substance, and a control region.

Plasma Membrane

The cell's outer boundary, called the **plasma membrane** (or the *cell membrane*), covers a cell's surface and acts as a barrier between the inside and the outside of a cell. All materials enter or exit through the plasma membrane. The surface of a plasma membrane is shown in Figure 4-6a.

Cytoplasm

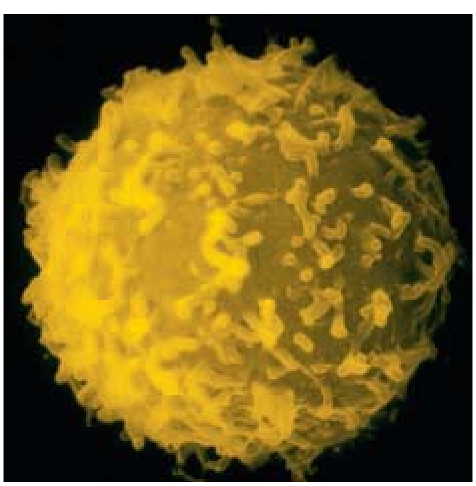
The region of the cell that is within the plasma membrane and that includes the fluid, the cytoskeleton, and all of the organelles except the nucleus is called the **cytoplasm.** The part of the cytoplasm that includes molecules and small particles, such as ribosomes, but not membrane-bound organelles is the **cytosol.** About 20 percent of the cytosol is made up of protein.

Control Center

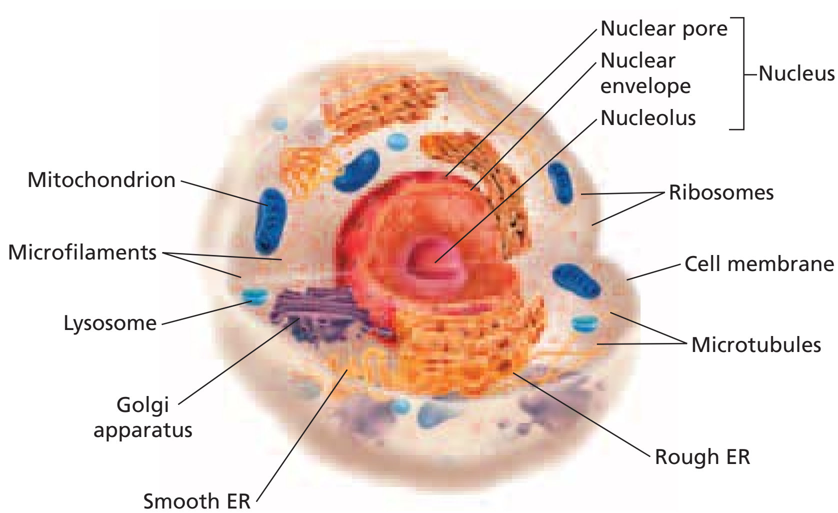
Cells carry coded information in the form of DNA for regulating their functions and reproducing themselves. The DNA in some types of cells floats freely inside the cell. Other cells have a membrane-bound organelle that contains a cell's DNA. This membrane-bound structure is called the **nucleus.** Most of the functions of a eukaryotic cell are controlled by the cell's nucleus. The nucleus is often the most prominent structure within a eukaryotic cell. It maintains its shape with the help of a protein skeleton called the *nuclear matrix.* The nucleus of a typical animal cell is shown in Figure 4-6b.

FIGURE 4-6

Most animal cells have a cell membrane, a nucleus, and a variety of other organelles embedded in a watery substance. The surface of the cell membrane can be seen in (a). The organelles inside the cell are labeled in the diagram (b).



(a)



(b)

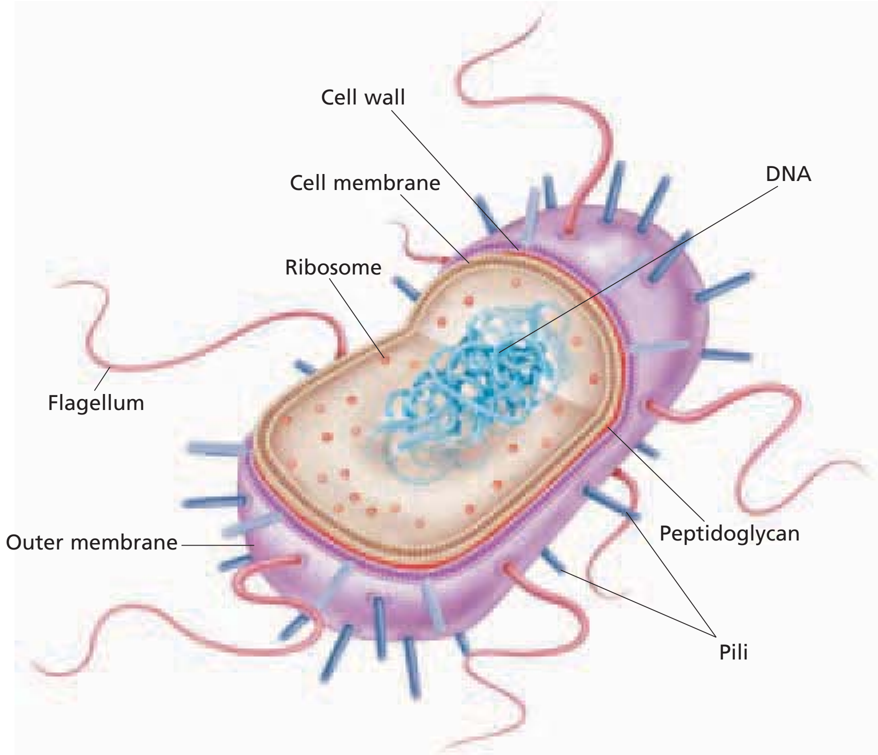


FIGURE 4-7

A prokaryotic cell lacks a membrane-bound nucleus and membrane-bound organelles. Most prokaryotic cells are much smaller than eukaryotic cells are.

TWO BASIC TYPES OF CELLS

Fossil evidence suggests that the earliest cells on Earth were simple cells similar to some present-day bacteria. As cells evolved, they differentiated into two major types: prokaryotes and eukaryotes.

Prokaryotes

Prokaryotes (proh-KAR-ee-OHTS) are organisms that lack a membrane-bound nucleus and membrane-bound organelles. Although prokaryotic cells lack a nucleus, their genetic information—in the form of DNA—is often concentrated in a part of the cell called the *nucleoid*. Figure 4-7 shows a typical prokaryotic cell. Prokaryotes are divided into two domains: Bacteria and Archaea (ahr-KEE-uh). The domain Bacteria includes organisms that are similar to the first cellular life-forms. The domain Archaea includes organisms that are thought to be more closely related to eukaryotic cells found in all other kingdoms of life.

Eukaryotes

Organisms made up of one or more cells that have a nucleus and membrane-bound organelles are called **eukaryotes** (yoo-KAR-ee-OHTS). Eukaryotic cells also have a variety of subcellular structures called **organelles,** well-defined, intracellular bodies that perform specific functions for the cell. Many organelles are surrounded by a membrane. The organelles carry out cellular processes just as a person's pancreas, heart, and other organs carry out a person's life processes. Eukaryotic cells are generally much larger than prokaryotic cells, as seen in Figure 4-8, which shows a white blood cell (eukaryote) destroying tiny bacterial cells (prokaryotes).

FIGURE 4-8

A white blood cell (eukaryotic) changes shape as it attacks purple-stained bacterial cells that are much smaller (prokaryotic).

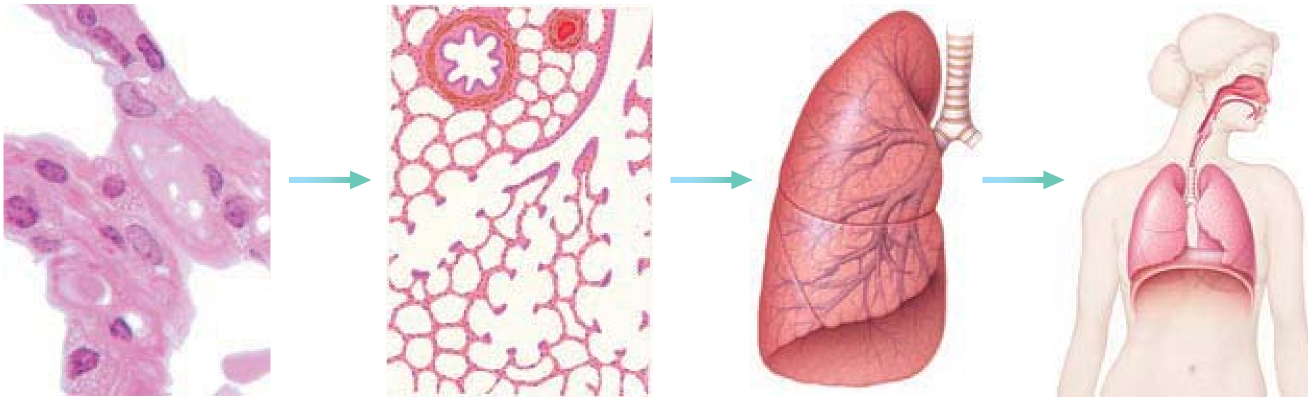


FIGURE 4-9

In a multicellular eukaryotic organisms, cells organize into tissues. Tissues organize into organs. Organs are part of organ systems, in which organs work together to perform body functions.

CELLULAR ORGANIZATION

Over time, cells began to form groups that functioned together. Some cells retained the ability to live outside a group. Others became dependent on each other for survival.

Colonies

A *colonial organism* is a collection of genetically identical cells that live together in a connected group. Colonial organisms are not truly multicellular because few cell activities are coordinated.

True Multicellularity

As organisms evolved, their cells became more specialized and eventually were unable to survive independently. Groups of cells took on specific roles within the organism. A group of similar cells and their products that carry out a specific function is called a **tissue.** Groups of tissues that perform a particular job in an organism are called **organs.** An **organ system** is a group of organs that accomplish related tasks. The stomach and liver are organs that are part of the digestive system. Finally, several organ systems combine to make up an organism. This hierarchical organization found in multicellular organisms is shown in Figure 4-9.

SECTION 2 REVIEW

1. Describe the relationship between a cell's shape and its function.
2. Explain the factor that limits cell size.
3. Identify the three main parts of an eukaryotic cell.
4. Summarize the differences between prokaryotic cells and eukaryotic cells.
5. List four levels of organization that combine to form an organism.

CRITICAL THINKING

6. **Making Calculations** If a cube-shaped cell grew from 1 cm per side to 3 cm per side, how much would its volume change?
7. **Forming Reasoned Opinions** Why do you think there are three basic structures common to all cell types? Support your answer.
8. **Analyzing Processes** How are the functions of prokaryotic cells controlled without a nucleus?

CELL ORGANELLES AND FEATURES

SECTION 3

Eukaryotic cells have many membrane systems. These membranes divide cells into compartments that function together to keep a cell alive.

PLASMA MEMBRANE

The plasma membrane (also called the *cell membrane*) has several functions. For example, it allows only certain molecules to enter or leave the cell. It separates internal metabolic reactions from the external environment. In addition, the plasma membrane allows the cell to excrete wastes and to interact with its environment.

Membrane Lipids

The plasma membrane, as well as the membranes of cell organelles, is made primarily of phospholipids. Phospholipids have a polar, hydrophilic ("water-loving") phosphate head and two nonpolar, hydrophobic ("water-fearing") fatty acid tails. Water molecules surround the plasma membrane. The phospholipids line up so that their heads point outward toward the water and their tails point inward, away from water. The result is a double layer called a **phospholipid bilayer,** as shown in Figure 4-10. The cell membranes of eukaryotes also contain lipids, called *sterols,* between the tails of the phospholipids. The major membrane sterol in animal cells is cholesterol. Sterols in the plasma membrane make the membrane more firm and prevent the membrane from freezing at low temperatures.

OBJECTIVES

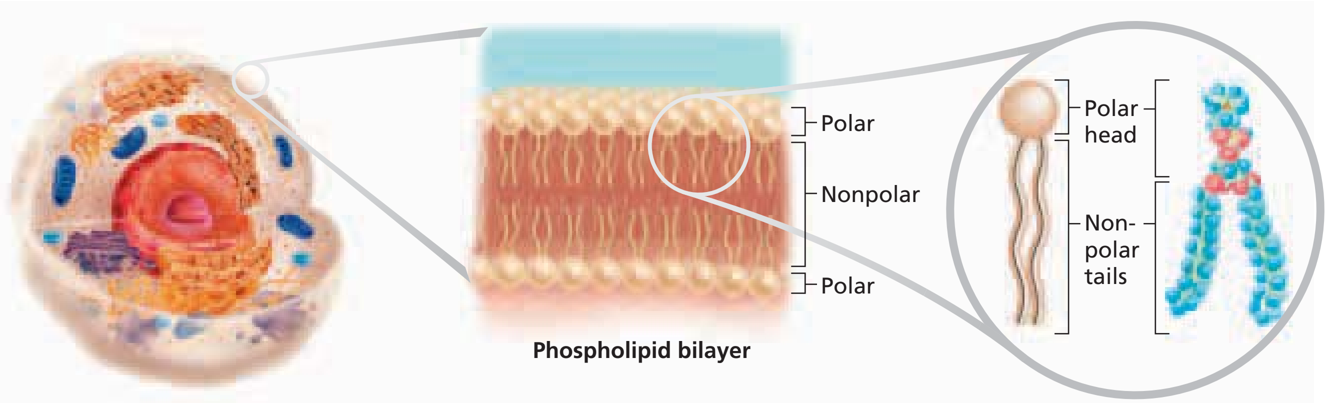
- **Describe** the structure and function of a cell's plasma membrane.
- **Summarize** the role of the nucleus.
- **List** the major organelles found in the cytosol, and describe their roles.
- **Identify** the characteristics of mitochondria.
- **Describe** the structure and function of the cytoskeleton.

VOCABULARY

phospholipid bilayer
chromosome
nuclear envelope
nucleolus
ribosome
mitochondrion
endoplasmic reticulum
Golgi apparatus
lysosome
cytoskeleton
microtubule
microfilament
cilium
flagellum
centriole

FIGURE 4-10

Cell membranes are made of a phospholipid bilayer. Each phospholipid molecule has a polar "head" and a two-part nonpolar "tail."



The phospholipid bilayer is the foundation of the cell membrane.

The arrangement of phospholipids in the bilayer makes the cell membrane selectively permeable.

A phospholipid's "head" is polar, and its two fatty acid "tails" are nonpolar.

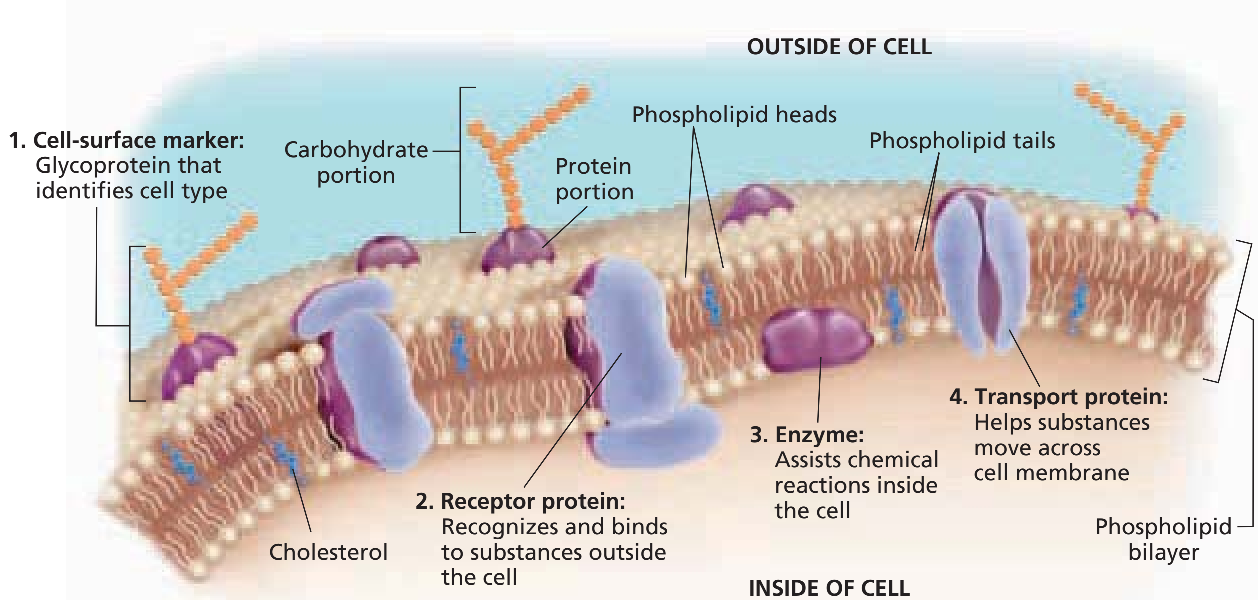


FIGURE 4-11

Cell membranes often contain proteins. Integral proteins include cell-surface markers, receptor proteins, and transport proteins. Enzymes are examples of peripheral proteins.

Membrane Proteins

Plasma membranes often contain specific proteins embedded within the lipid bilayer. These proteins are called *integral proteins*. Figure 4-11 shows that some integral proteins, such as cell surface markers, emerge from only one side of the membrane. Others, such as receptor proteins and transport proteins, extend across the plasma membrane and are exposed to both the cell's interior and exterior environments. Proteins that extend across the plasma membrane are able to detect environmental signals and transmit them to the inside of the cell. *Peripheral proteins,* such as the enzyme shown in Figure 4-11, lie on only one side of the membrane and are not embedded in it.

As Figure 4-11 shows, integral proteins exposed to the cell's external environment often have carbohydrates attached. These carbohydrates can act as labels on cell surfaces. Some labels help cells recognize each other and stick together. Viruses can use these labels as docks for entering and infecting cells.

Integral proteins play important roles in actively transporting molecules into the cell. Some act as channels or pores that allow certain substances to pass. Other integral proteins bind to a molecule on the outside of the cell and then transport it through the membrane. Still others act as sites where chemical messengers such as hormones can attach.

Fluid Mosaic Model

A cell's plasma membrane is surprisingly dynamic. Scientists describe the cell membrane as a fluid mosaic. The *fluid mosaic model* states that the phospholipid bilayer behaves like a fluid more than it behaves like a solid. The membrane's lipids and proteins can move laterally within the bilayer, like a boat on the ocean. As a result of such lateral movement, the pattern, or "mosaic," of lipids and proteins in the cell membrane constantly changes.

NUCLEUS

Most of the functions of a eukaryotic cell are controlled by the nucleus, shown in Figure 4-12. The nucleus is filled with a jellylike liquid called the *nucleoplasm,* which holds the contents of the nucleus and is similar in function to a cell's cytoplasm.

The nucleus houses and protects the cell's genetic information. The hereditary information that contains the instructions for the structure and function of the organism is coded in the organism's DNA, which is contained in the nucleus. When a cell is not dividing, the DNA is in the form of a threadlike material called *chromatin.* When a cell is about to divide, the chromatin condenses to form **chromosomes.** Chromosomes are structures in the nucleus made of DNA and protein.

The nucleus is the site where DNA is transcribed into ribonucleic acid (RNA). RNA moves through nuclear pores to the cytoplasm, where, depending on the type of RNA, it carries out its function.

Nuclear Envelope

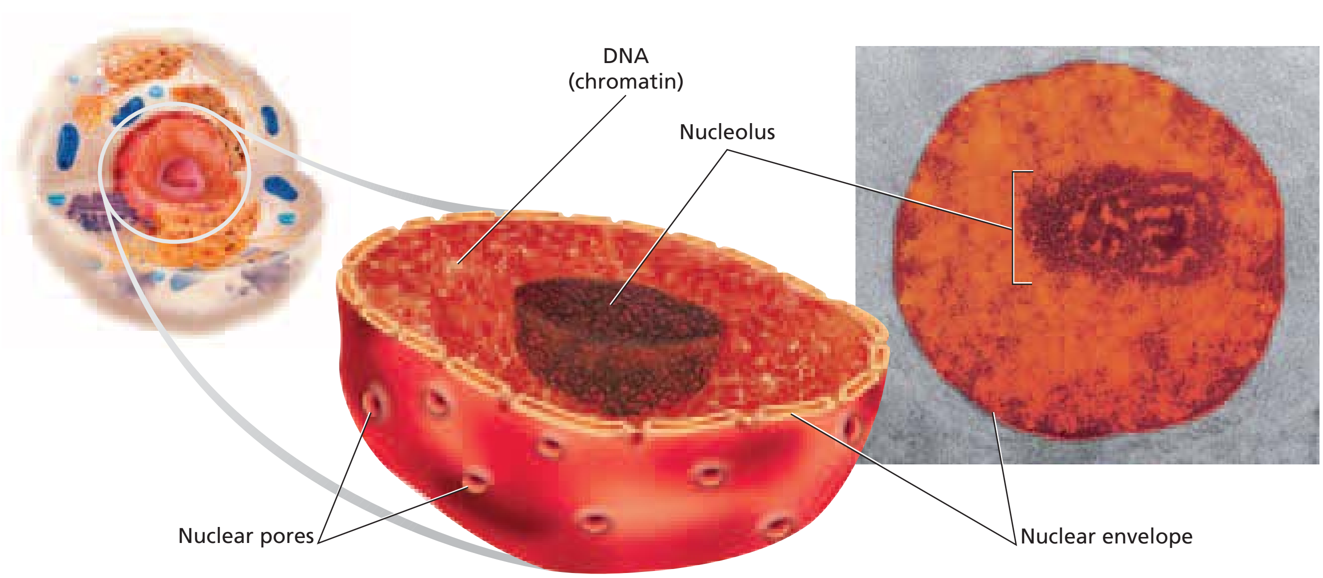
The nucleus is surrounded by a double membrane called the **nuclear envelope.** The nuclear envelope is made up of two phospholipid bilayers. Covering the surface of the nuclear envelope are tiny, protein-lined holes, which are called *nuclear pores*. The nuclear pores provide passageways for RNA and other materials to enter and leave the nucleus.

Nucleolus

Most nuclei contain at least one denser area, called the **nucleolus** (noo-KLEE-uh-luhs). The nucleolus (plural, *nucleoli*) is the site where DNA is concentrated when it is in the process of making ribosomal RNA. **Ribosomes** (RIE-buh-SOHMZ) are organelles made of protein and RNA that direct protein synthesis in the cytoplasm.

FIGURE 4-12

The nucleus of a cell is surrounded by a double membrane called the nuclear envelope. The nucleus stores the cell's DNA.



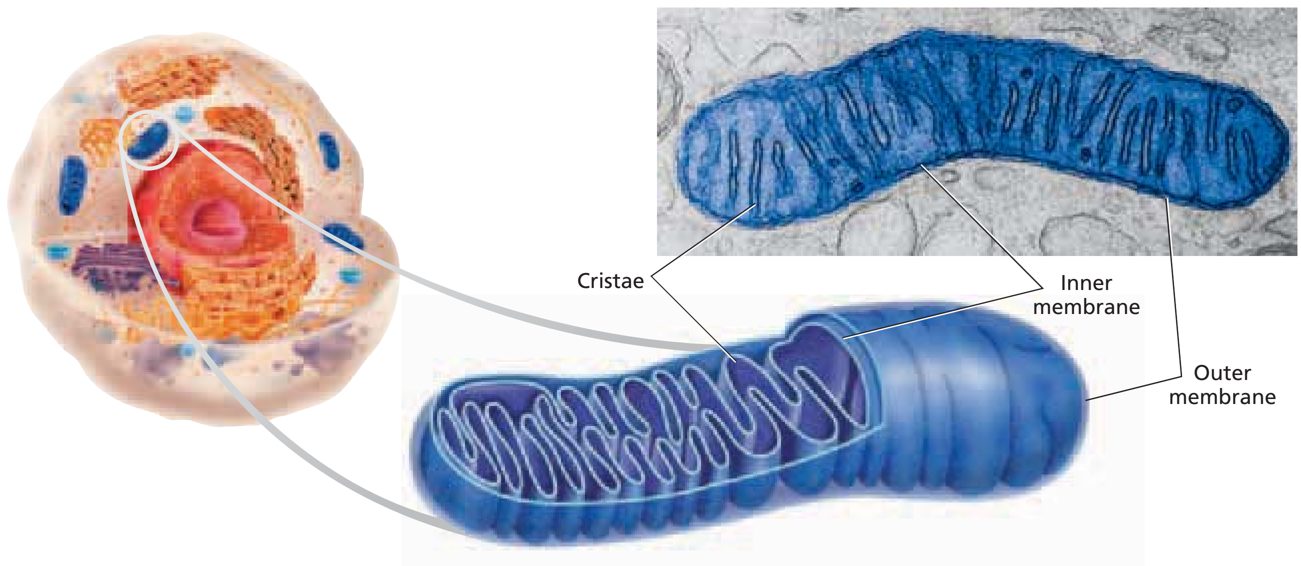


FIGURE 4-13
Mitochondria convert organic molecules into energy for the cell. Mitochondria have an inner membrane and an outer membrane. The folds of the inner membrane, called *cristae*, are the site of energy conversion.

MITOCHONDRIA

Mitochondria (MIET-oh-KAHN-dree-uh) (singular, *mitochondrion*) are tiny organelles that transfer energy from organic molecules to adenosine triphosphate (ATP). ATP ultimately powers most of the cell's chemical reactions. Highly active cells, such as muscle cells, can have hundreds of mitochondria. Cells that are not very active, such as fat-storage cells, have few mitochondria.

Like a nucleus, a mitochondrion has an inner and an outer phospholipid membrane, as shown in Figure 4-13. The outer membrane separates the mitochondrion from the cytosol. The inner membrane has many folds, called *cristae* (KRIS-tee). Cristae contain proteins that carry out energy-harvesting chemical reactions.

Mitochondrial DNA

Mitochondria have their own DNA and can reproduce only by the division of preexisting mitochondria. Scientists think that mitochondria originated from prokaryotic cells that were incorporated into ancient eukaryotic cells. This symbiotic relationship provided the prokaryotic invaders with a protected place to live and provided the eukaryotic cell with an increased supply of ATP.

FIGURE 4-14
Ribosomes are the organelles responsible for building protein. Ribosomes have a large and small subunit, each made of protein and ribosomal RNA. Some ribosomes are free in the cell. Others are attached to the rough endoplasmic reticulum.

RIBOSOMES

Ribosomes are small, roughly spherical organelles that are responsible for building protein. Ribosomes do not have a membrane. They are made of protein and RNA molecules. Ribosome assembly begins in the nucleolus and is completed in the cytoplasm. One large and one small subunit come together to make a functioning ribosome, shown in Figure 4-14. Some ribosomes are free within the cytosol. Others are attached to the rough endoplasmic reticulum.

ENDOPLASMIC RETICULUM

The **endoplasmic reticulum** (EN-doh-PLAZ-mik ri-TIK-yuh-luhm), abbreviated ER, is a system of membranous tubes and sacs, called *cisternae* (sis-TUHR-nee). The ER functions primarily as an intracellular highway, a path along which molecules move from one part of the cell to another. The amount of ER inside a cell fluctuates, depending on the cell's activity. There are two types of ER: rough and smooth. The two types of ER are thought to be continuous.

Word Roots and Origins

reticulum

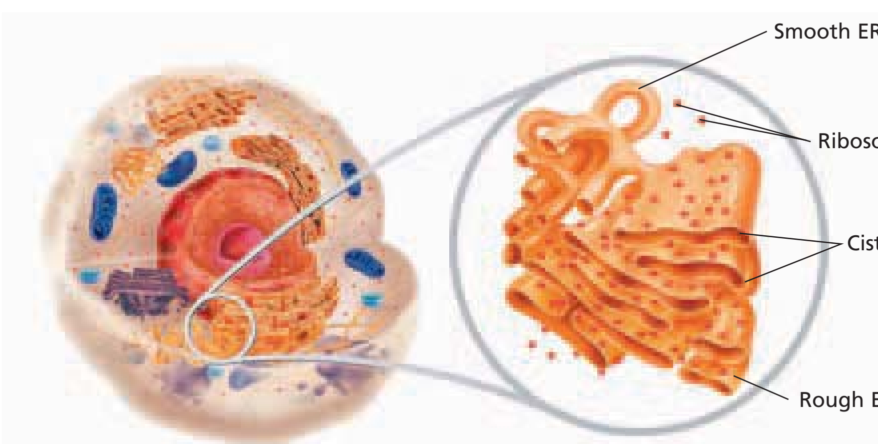
from the Latin *rete,* meaning "net"; *reticulum* means "little net"

Rough Endoplasmic Reticulum

The rough endoplasmic reticulum is a system of interconnected, flattened sacs covered with ribosomes, as shown in Figure 4-15. The rough ER produces phospholipids and proteins. Certain types of proteins are made on the rough ER's ribosomes. These proteins are later exported from the cell or inserted into one of the cell's own membranes. For example, ribosomes on the rough ER make digestive enzymes, which accumulate inside the endoplasmic reticulum. Little sacs or vesicles then pinch off from the ends of the rough ER and store the digestive enzymes until they are released from the cell. Rough ER is most abundant in cells that produce large amounts of protein for export, such as cells in digestive glands and antibody-producing cells.

Smooth Endoplasmic Reticulum

The smooth ER lacks ribosomes and thus has a smooth appearance. Most cells contain very little smooth ER. Smooth ER builds lipids such as cholesterol. In the ovaries and testes, smooth ER produces the steroid hormones estrogen and testosterone. In skeletal and heart muscle cells, smooth ER releases calcium, which stimulates contraction. Smooth ER is also abundant in liver and kidney cells, where it helps detoxify drugs and poisons. Long-term abuse of alcohol and other drugs causes these cells to produce more smooth ER. Increased amounts of smooth ER in liver cells is one of the factors that can lead to drug tolerance. As Figure 4-15 shows, rough ER and smooth ER form an interconnected network.



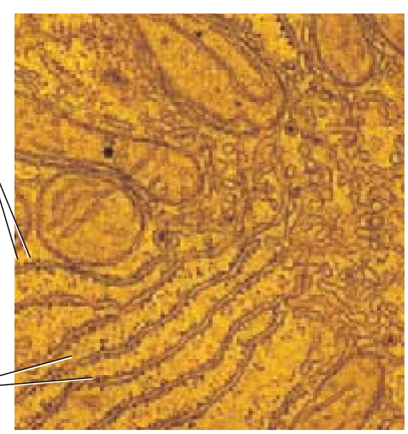


FIGURE 4-15

The endoplasmic reticulum (ER) serves as a site of synthesis for proteins, lipids, and other materials. The dark lines in the photo represent the membranes of the ER, and the narrow lighter areas between the dark lines show the channels and spaces (cisternae) inside the ER.

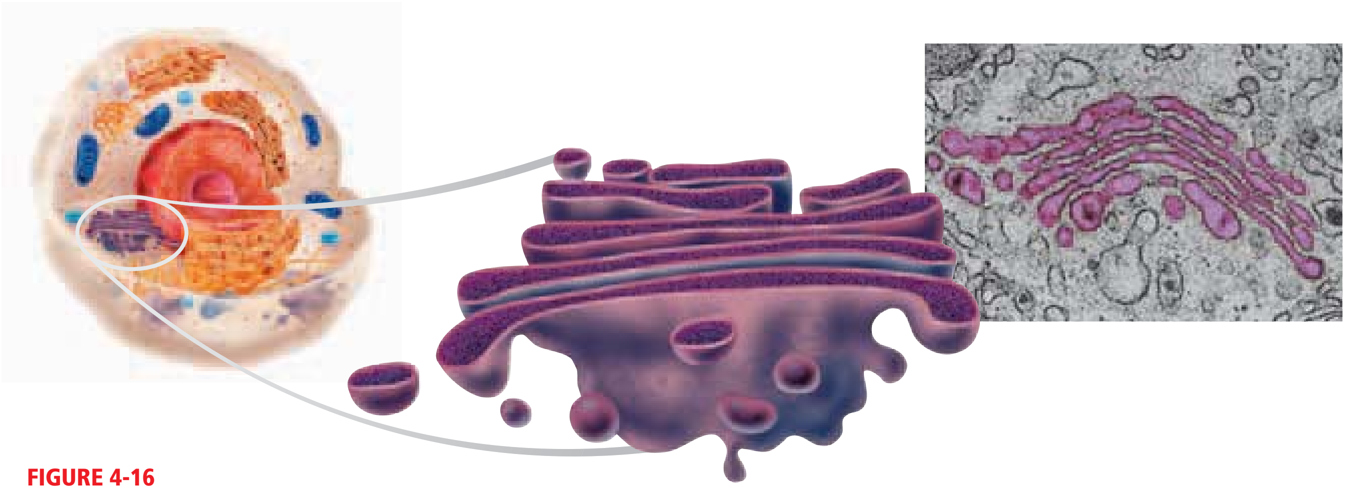


FIGURE 4-16

The Golgi apparatus modifies many cellular products and prepares them for export.

GOLGI APPARATUS

The **Golgi apparatus,** shown in Figure 4-16, is another system of flattened, membranous sacs. The sacs nearest the nucleus receive vesicles from the ER containing newly made proteins or lipids. Vesicles travel from one part of the Golgi apparatus to the next and transport substances as they go. The stacked membranes modify the vesicle contents as they move along. The proteins get “address labels” that direct them to various other parts of the cell. During this modification, the Golgi apparatus can add carbohydrate labels to proteins or alter new lipids in various ways.

VESICLES

Cells contain several types of vesicles, which perform various roles. Vesicles are small, spherically shaped sacs that are surrounded by a single membrane and that are classified by their contents. Vesicles often migrate to and merge with the plasma membrane. As they do, they release their contents to the outside of the cell.

Lysosomes

Lysosomes (LIE-suh-SOHMZ) are vesicles that bud from the Golgi apparatus and that contain digestive enzymes. These enzymes can break down large molecules, such as proteins, nucleic acids, carbohydrates, and phospholipids. In the liver, lysosomes break down glycogen in order to release glucose into the bloodstream. Certain white blood cells use lysosomes to break down bacteria. Within a cell, lysosomes digest worn-out organelles in a process called *autophagy* (aw-TAHF-uh-jee).

Lysosomes are also responsible for breaking down cells when it is time for the cells to die. The digestion of damaged or extra cells by the enzymes of their own lysosomes is called *autolysis* (aw-TAHL-uh-sis). Lysosomes play a very important role in maintaining an organism’s health by destroying cells that are no longer functioning properly.

Peroxisomes

Peroxisomes are similar to lysosomes but contain different enzymes and are not produced by the Golgi apparatus. Peroxisomes are abundant in liver and kidney cells, where they neutralize free radicals (oxygen ions that can damage cells) and detoxify alcohol and other drugs. Peroxisomes are named for the hydrogen peroxide, H_2O_2, they produce when breaking down alcohol and killing bacteria. Peroxisomes also break down fatty acids, which the mitochondria can then use as an energy source.

Other Vesicles

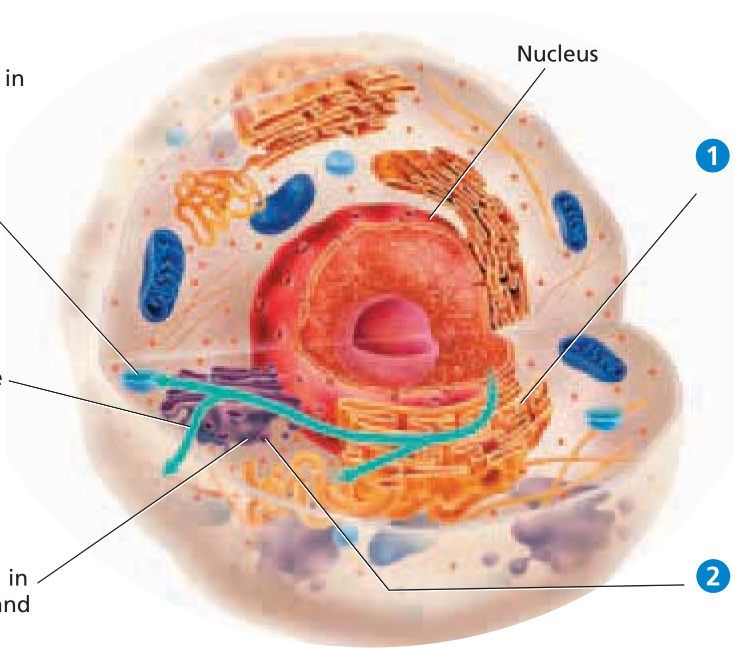
Specialized peroxisomes, called *glyoxysomes,* can be found in the seeds of some plants. They break down stored fats to provide energy for the developing plant embryo. Some cells engulf material by surrounding it with plasma membrane. The resulting pocket buds off to become a vesicle inside the cell. This vesicle is called an *endosome*. Lysosomes fuse with endosomes and digest the engulfed material. Food vacuoles are vesicles that store nutrients for a cell. Contractile vacuoles are vesicles that can contract and dispose of excess water inside a cell.

Protein Synthesis

One of the major functions of a cell is the production of protein. The path some proteins take from synthesis to export can be seen in Figure 4-17. In step 1, proteins are assembled by ribosomes on the rough ER. Then, in step 2, vesicles transport proteins to the Golgi apparatus. In step 3, the Golgi modifies proteins and packages them in new vesicles. In step 4, vesicles release proteins that have destinations outside the cell. In step 5, vesicles containing enzymes remain inside the cell as lysosomes, peroxisomes, endosomes, or other types of vesicles.

FIGURE 4-17

The rough ER, Golgi apparatus, and vesicles work together to transport proteins to their destinations inside and outside the cell.



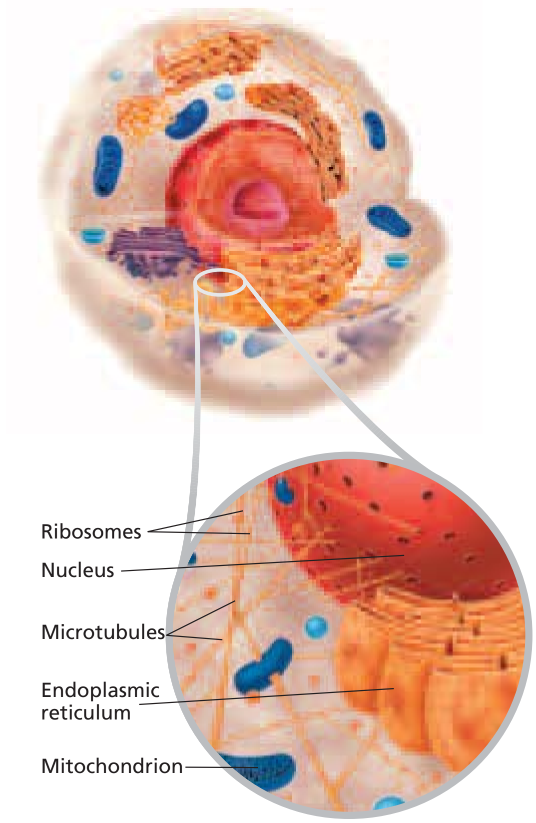


FIGURE 4-18

Microtubules provide a path for organelles and molecules as they move throughout the cell.

CYTOSKELETON

The **cytoskeleton** is a network of thin tubes and filaments that crisscrosses the cytosol. The tubes and filaments give shape to the cell from the inside in the same way that tent poles support the shape of a tent. The cytoskeleton also acts as a system of internal tracks, shown in Figure 4-18, on which items move around inside the cell. The cytoskeleton's functions are based on several structural elements. Three of these are microtubules, microfilaments, and intermediate filaments, shown and described in Table 4-2.

Microtubules

Microtubules are hollow tubes made of a protein called *tubulin*. Each tubulin molecule consists of two slightly different subunits. Microtubules radiate outward from a central point called the *centrosome* near the nucleus. Microtubules hold organelles in place, maintain a cell's shape, and act as tracks that guide organelles and molecules as they move within the cell.

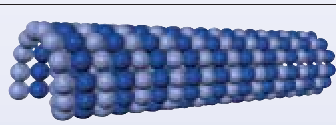
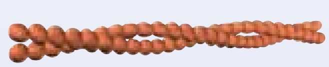
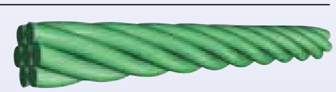
Microfilaments

Finer than microtubules, **microfilaments** are long threads of the beadlike protein actin and are linked end to end and wrapped around each other like two strands of a rope. Microfilaments contribute to cell movement, including the crawling of white blood cells and the contraction of muscle cells.

Intermediate Filaments

Intermediate filaments are rods that anchor the nucleus and some other organelles to their places in the cell. They maintain the internal shape of the nucleus. Hair-follicle cells produce large quantities of intermediate filament proteins. These proteins make up most of the hair shaft.

TABLE 4-2 ***The Structure of the Cytoskeleton***

Property	Microtubules	Microfilaments	Intermediate filaments
Structure	hollow tubes made of coiled protein	two strands of intertwined protein	protein fibers coiled into cables
Protein subunits	tubulin, with two subunits: α and β tubulin	actin	one of several types of fibrous proteins
Main function	maintenance of cell shape; cell motility (in cilia and flagella); chromosome movement; organelle movement	maintenance and changing of cell shape; muscle contraction; movement of cytoplasm; cell motility; cell division	maintenance of cell shape; anchor nucleus and other organelles; maintenance of shape of nucleus
Shape			

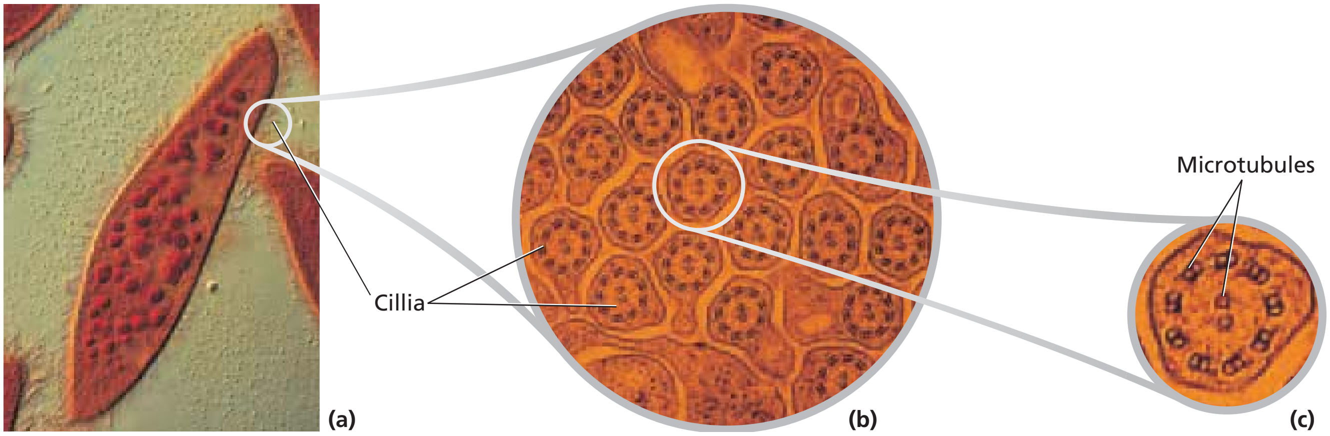


FIGURE 4-19
A SEM of a paramecium shows cilia on the surface of the cell (a). A TEM of a cross section of those cilia (b) reveals the internal structure of the cilia. The characteristic 9+2 configuration of microtubules can be clearly seen (c).

Cilia and Flagella

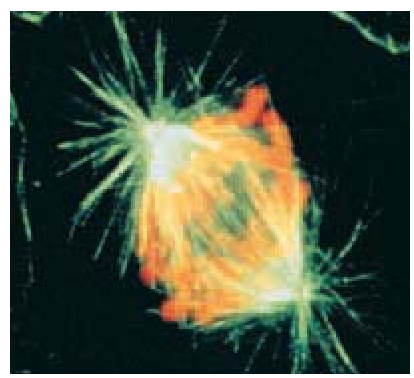
Cilia (SIL-ee-uh) and **flagella** (fluh-JEL-uh) are hairlike structures that extend from the surface of the cell, where they assist in movement. Cilia are short and are present in large numbers on certain cells, whereas flagella are longer and are far less numerous on the cells where they occur. Cilia and flagella have a membrane on their outer surface and an internal structure of nine pairs of microtubules around two central tubules, as Figure 4-19 shows.

Cilia on cells in the inner ear vibrate and help detect sound. Cilia cover the surfaces of many protists and "row" the protists through water like thousands of oars. On other protists, cilia sweep water and food particles into a mouthlike opening. Many kinds of protists use flagella to propel themselves, as do human sperm cells.

Centrioles

Centrioles consist of two short cylinders of microtubules at right angles to each other and are situated in the cytoplasm near the nuclear envelope. Centrioles occur in animal cells, where they organize the microtubules of the cytoskeleton during cell division, as shown in Figure 4-20. Plant cells lack centrioles. Basal bodies have the same structure that centrioles do. Basal bodies are found at the base of cilia and flagella and appear to organize the development of cilia and flagella.

FIGURE 4-20
During cell division, centrioles organize microtubules that pull the chromosomes (orange) apart. The centrioles are at the center of rays of microtubules, which have been stained green with a fluorescent dye.



SECTION 3 REVIEW

1. Explain how the fluid mosaic model describes the plasma membrane.
2. List three cellular functions that occur in the nucleus.
3. Describe the organelles that are found in a eukaryotic cell.
4. Identify two characteristics that make mitochondria different from other organelles.
5. Contrast three types of cytoskeletal fibers.

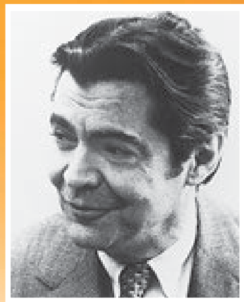
CRITICAL THINKING

6. **Relating Concepts** If a cell has a high energy requirement, would you expect the cell to have many mitochondria or few mitochondria? Why?
7. **Analyzing Information** How do scientists think that mitochondria originated? Why?
8. **Analyzing Statements** It is not completely accurate to say that organelles are floating freely in the cytosol. Why not?

Science in Action

How Do Cells Secrete Proteins?

The invention of electron microscopes allowed biologists to see the detail of the tiny structures inside cells. But it was clever experimentation by George Palade that revealed how those tiny structures help a cell survive.



George Palade

HYPOTHESIS: Membranous Organelles Secrete Proteins

Six years after he graduated from medical school in Romania, George Palade began conducting research at the Rockefeller Institute for Medical Research in New York City. He studied the network of membranous organelles in cells of the guinea pig pancreas. This network included the rough endoplasmic reticulum (ER), the smooth ER, the Golgi apparatus, lysosomes, and secretory granules.

Palade knew about the structure of these organelles. He also knew that ribosomes on the rough ER were associated with making proteins. But what Palade and other scientists did not know was how the proteins were secreted from cells once they were made on the ribosomes. Palade suspected that the membranous organelles played a role.

METHODS: Track Proteins

Part of Palade's genius was inventing a way to make thin slices of tissue from a guinea pig's pancreas and keep the cells of the tissue alive. He also developed a way to track newly made proteins, a method called the *pulse-chase technique.* With this technique, Palade added "labeled" amino acids (made with radioactive atoms) to the pancreas cells for a fixed amount of time. This was the "pulse." The cells used the labeled amino acids and their own "unlabeled" amino acids (without radioactive atoms) to make proteins. Palade would then "chase" out any labeled amino acid that the cells had not used to build proteins by adding an excess of unlabeled amino acid.

RESULTS: Black Dots Move as Time Passes

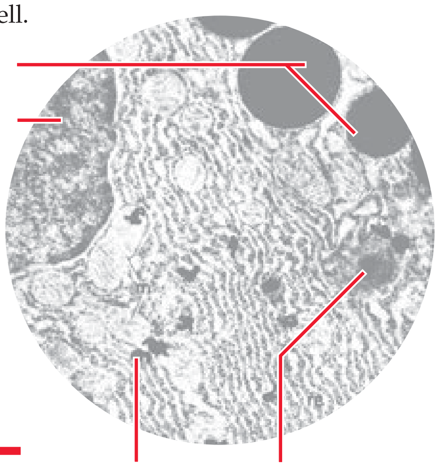
At first, the black dots that represented labeled amino acids were found in the rough ER. Photos taken at later time periods showed the black dots in vesicles close to smooth ER, then in smooth ER, then in the Golgi apparatus, and finally in vesicles close to the edge of the cell.

CONCLUSION: Secreted Proteins Follow a Specific Path

Palade concluded that secreted proteins move from the rough ER to the smooth ER in vesicles that are pinched off from the rough ER membrane. The proteins then move from the smooth ER to the Golgi apparatus (again, in vesicles). From the Golgi apparatus, the proteins move in vesicles to the edge of the cell. Finally, the vesicles fuse with the plasma membrane.

Further Experiments and a Nobel Prize

Palade published the work in 1964. In 1974, George Palade and two other researchers, Albert Claude and Christian De Duve, were awarded the Nobel Prize in medicine for their discoveries about the organization of the cell.



The black dots in the cell (labeled amino acid) are the black dots Palade found in his pulse-chase experiments at the end of a 3 minute pulse. At this time, most of the black dots are found in the rough ER.

REVIEW

1. What did the pulse-chase experiments allow Palade to observe?
2. Summarize the results of Palade's pulse-chase experiments.
3. **Critical Thinking** Was it important to use living tissue for the experiments?

SCI LINKS
www.scilinks.org
Topic: Exocytosis and Endocytosis
Keyword: HM60554

SECTION 4

UNIQUE FEATURES OF PLANT CELLS

Plant cells have three kinds of structures that are not found in animal cells and that are extremely important to plant survival: plastids, central vacuoles, and cell walls.

OBJECTIVES

- **List** three structures that are present in plant cells but not in animal cells.
- **Compare** the plasma membrane, the primary cell wall, and the secondary cell wall.
- **Explain** the role of the central vacuole.
- **Describe** the roles of plastids in the life of a plant.
- **Identify** features that distinguish prokaryotes, eukaryotes, plant cells, and animal cells.

VOCABULARY

cell wall
central vacuole
plastid
chloroplast
thylakoid
chlorophyll

PLANT CELLS

Most of the organelles and other parts of the cell just described are common to all eukaryotic cells. However, plant cells have three additional kinds of structures that are extremely important to plant function: cell walls, large central vacuoles, and plastids.

To understand why plant cells have structures not found in animal cells, consider how a plant's lifestyle differs from an animal's. Plants make their own carbon-containing molecules directly from carbon taken in from the environment. Plant cells take carbon dioxide gas from the air, and in a process called *photosynthesis,* they convert carbon dioxide and water into sugars. The organelles and structures in plant cells are shown in Figure 4-21.

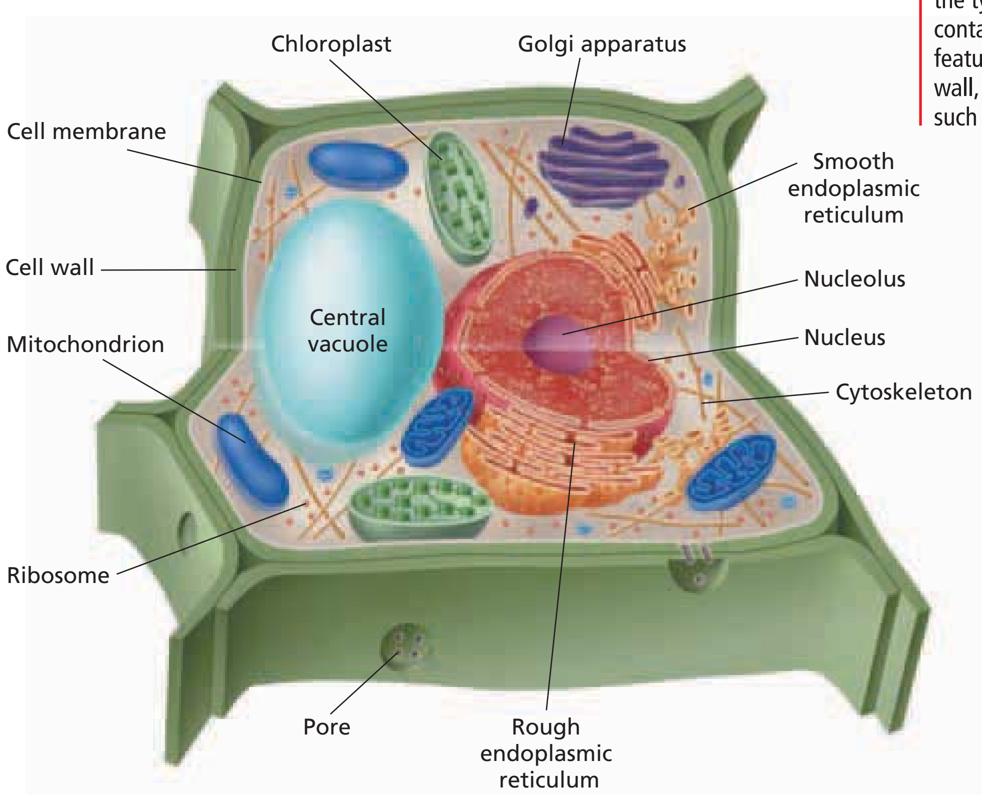


FIGURE 4-21

In addition to containing almost all of the types of organelles that animal cells contain, plant cells contain three unique features. Those features are the cell wall, the central vacuole, and plastids, such as chloroplasts.