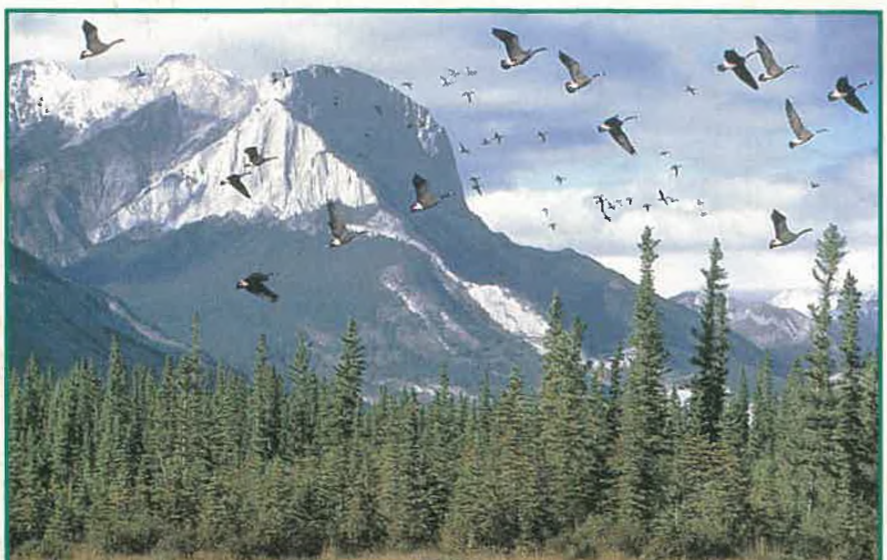
Unit 1

BIOLOGICAL PRINCIPLES

CHAPTERS

"*Our ideas are only instruments which we use to break into phenomena; we must change them when they have served their purpose, as we change a blunt lancet that we have used long enough.*"

Claude Bernard



Organisms living in this taiga ecosystem are adapted for dry, cold weather and reduced availability of food in winter.

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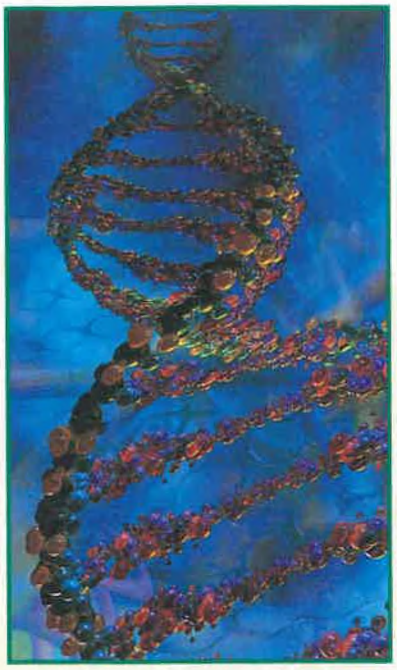
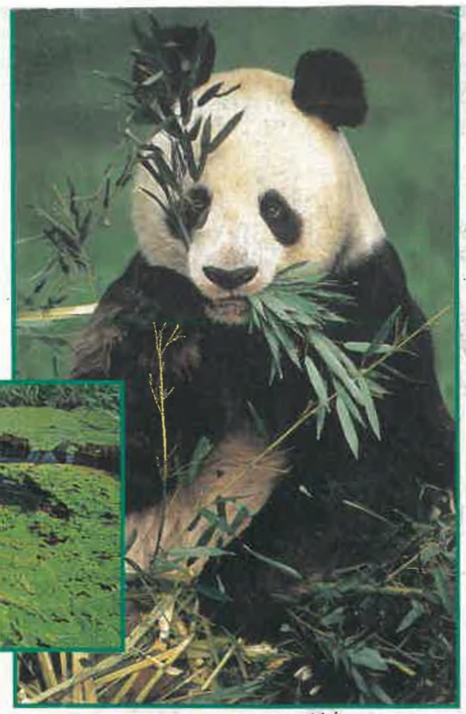
National Science Teachers Association sciLINKS Internet resources are located throughout this unit.



DNA is responsible for transmitting genetic information to offspring.



This giant panda gets its energy by eating bamboo leaves. The Amazon water lily, above left, lives in shallow eutrophic ponds.

Red-eyed tree frog

CHAPTER 1

THE SCIENCE OF LIFE

Snowy owls, Nyctea scandiaca, *live on the open tundra and build their nests on the ground. This juvenile owl hatched in a flower-filled alpine meadow.*

FOCUS CONCEPT: *Biological Themes and Processes*

As you read, take note of the recurring themes of biology and the characteristics that all organisms share.

THEMES OF BIOLOGY

Scientists estimate that 40 million species of organisms inhabit the Earth. But of these 40 million species, only about 2 million have been identified and named, and only a few thousand have been studied in any detail. Thus, much of the world of biology remains to be explored and studied. Fortunately, there are guideposts to help chart a course through this vast and fascinating world. These guideposts are the themes that unify biology. In this chapter, you will read about the unifying themes of biology that allow biologists to study the enormous diversity of life.

SECTION

1-1

OBJECTIVES

▲ List six unifying themes of biology.

● Explain how organisms get the energy they need to survive.

■ Describe the main difference between the structure of a living thing and that of a nonliving thing.

THE STUDY OF LIFE

The first life-form probably arose on Earth more than 3.5 billion years ago. Much evidence suggests that this first **organism**—or living thing—was a single cell, too small to be seen without the aid of a microscope. For millions of years, single-celled organisms floating in the seas were the only life on Earth. No fish swam in the oceans, no birds flew through the air, and no snakes moved across the ground.

Over time, organisms changed. New kinds of organisms arose from older kinds and came to inhabit almost every region of the Earth. Today brilliantly colored birds glide through the trees of tropical rain forests. Odd-looking fish prowl the dark depths of the oceans, emitting a strange red light that helps them locate their prey. Giant sequoia trees tower hundreds of feet above the ferns growing on the forest floors. Nearly blind moles burrow their way underground searching for tiny insects to consume.

These and millions of other types of organisms form the diverse population of Earth. **Biology**—the science of life—is the study of all living things. Biology includes the study of the microscopic structure of single cells. It also includes the study of the global interactions of millions of organisms. It includes the study of the life history of individual organisms as well as the collective history of all organisms.

The science of biology is as varied as the organisms that are its subjects. (Compare the owl shown on the facing page with the algae shown in Figure 1-1.) Biology is unified by certain themes, however, that come into play no matter what organism or what kind of

FIGURE 1-1

This microscopic unicellular alga, *Eremoophaera* sp. (LM, 31×), lives in a water environment. It, together with the owl shown on the facing page, gives an indication of the great diversity found in the living world.

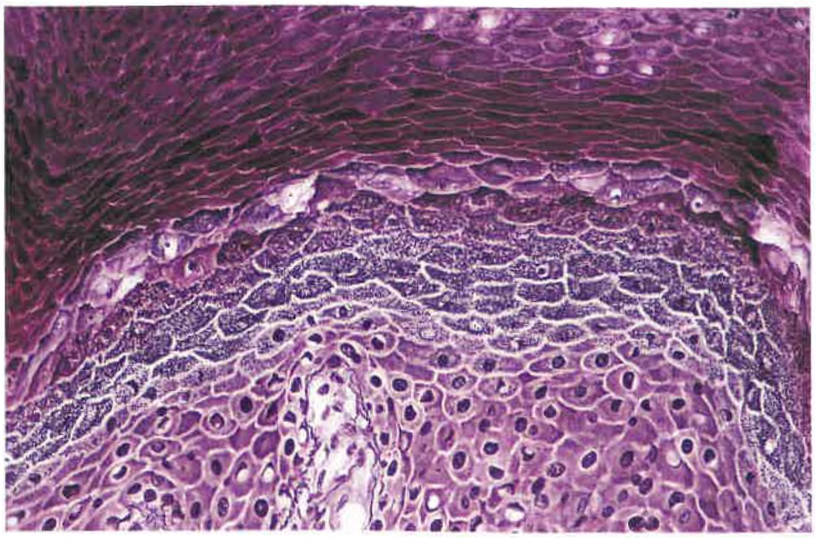


FIGURE 1-2

These tightly packed cells are from a thin section of human skin (LM 240×). There are many different kinds of cells in animal bodies.

interaction is studied. Six major themes recur throughout this book: (1) cell structure and function, (2) stability and homeostasis, (3) reproduction and inheritance, (4) evolution, (5) interdependence of organisms, and (6) matter, energy, and organization. The paragraphs that follow will give you a brief introduction to each theme. You will get a closer look at each theme in later chapters of this book. By reflecting on these themes in your study of biology, you will recognize the patterns that connect all life-forms.

Cell Structure and Function

The cell is the basic unit of life. All organisms are made of and develop from cells. Some organisms are composed of only one cell. These organisms are called **unicellular** (YOON-uh-SEL-yoo-luhr) **organisms.** Most of the living things that you see around you are **multicellular** (MUHL-ti-SEL-yoo-luhr) **organisms.** That is, they are composed of more than one cell.

Cells are small but highly organized. They contain specialized structures that carry out the cell's life processes. There are many different kinds of cells, but all cells are similar in several ways. They are surrounded by a membrane and contain a set of instructions—in the form of genetic information—necessary for making new cell parts, as well as new cells, from the molecules the cell takes in.

Look again at Figure 1-1, and compare the unicellular organism with the cells shown in Figure 1-2. New cells produced by unicellular organisms are virtually identical to the parent unicellular organisms that produced them. In contrast, mature multicellular organisms, which also begin their lives as one cell, contain not only *many* cells but also many different *kinds* of cells. The cells of multicellular organisms underwent **differentiation.** That is, they became different from each other as they multiplied and followed the various roles supplied for them by their genetic instructions.

Stability and Homeostasis

Living things, from single cells to entire large organisms, maintain very stable internal conditions. You know that the human body operates within a very narrow temperature range, around 37°C (98.6°F). Animal bodies like yours have systems that maintain internal conditions, such as temperature, water content, and even food intake, at very stable levels. This stable level of internal conditions, called **homeostasis** (HOH-mee-oh-STAY-sis), is found in all living things, including single cells.

Quick Lab

Observing Homeostasis

Materials 500 mL beakers (3), wax pen, tap water, thermometer, ice, hot water, goldfish, small dip net, watch or clock with a second hand

Procedure

1. Use a wax pen to label three 500 mL beakers as follows: 27°C (80°F), 20°C (68°F), and 10°C (50°F). Put 250 mL of tap water in each beaker. Use hot water or ice to adjust the temperature of the water in each beaker to the temperature indicated on the label.
2. Put the goldfish in the beaker of 27°C water. Record the number of times the gills move in 1 minute.
3. Move the goldfish to the beaker of 20°C water. Repeat observations. Move the goldfish to the beaker of 10°C water. Repeat observations.

Analysis What happens to the rate at which gills move when the temperature changes? Why? How do gills help fish maintain homeostasis?

The seal shown in Figure 1-3 can keep its body temperature very stable in a variety of water temperatures, even in very cold water. It takes in enough food to maintain a thick layer of fat under its skin for insulation. Blood flow through the seal's body, and in its flippers, is adjusted according to the temperature of the water it swims in. Its body can conserve or release heat as needed to remain at a stable temperature.

FIGURE 1-3

The shape and composition of the body of this harp seal, *Phoca groenlandica*, together with its efficient, heat-conserving circulatory system, allow the seal to survive in water temperatures that would kill many other animals.

Reproduction and Inheritance

All organisms produce new organisms like themselves. In this process, called **reproduction,** organisms transmit hereditary information to their offspring. This hereditary information is in the form of a large molecule called deoxyribonucleic acid, or **DNA.** In multicellular organisms and in some unicellular organisms, DNA is enclosed within a structure made of membrane. In other unicellular organisms, DNA exists as a loop, like the one shown in Figure 1-4. A short segment of DNA that contains the instructions for the development of a single trait of an organism is called a **gene.**

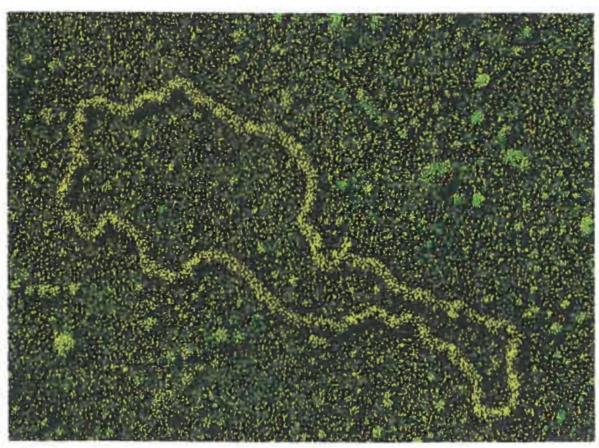
The DNA of a cell is like a large library. It contains all of the books of instructions—genes—that the cell will ever need. In this way, the cell can make the structures and complex chemicals necessary for life. In multicellular organisms, the DNA of every body cell, even different kinds of body cells, is identical. Each cell uses certain genes from the complete set. For example, cells in your thyroid gland use the set of genes from your DNA that are instructions for making thyroid hormone. Your other body cells ignore these instructions and use only the genes appropriate to their particular functions.

In **sexual reproduction,** hereditary information from two parts of a single organism or from two organisms of the same species is combined. When an egg of a female leopard frog is fertilized by the sperm of a male leopard frog, the egg and sperm join to form a single cell. This joining produces a fertilized egg cell that contains hereditary information from both the female parent and the male parent. This cell begins a series of cell divisions to produce a new leopard frog. With each division, every new cell receives a complete copy of the same hereditary information. Thus, the new organism is composed of cells that contain complete sets of hereditary information from both of its parents.

In **asexual reproduction,** hereditary information from different organisms is not combined. For example, when a bacterium reproduces asexually, it splits in two. As a result, one cell gives rise to two cells. Each of the two cells contains an identical copy of the hereditary information from the original bacterium.

FIGURE 1-4

A loop of DNA (SEM 72,000×) contains the genetic information of the unicellular organism that it is found in. Many genes are linked in the DNA loop.



Evolution

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Populations of organisms **evolve,** or change, over generations. The study of **evolution** helps us understand how the many kinds of organisms that have lived on Earth came into existence. It also explains how organisms alive today are related to those that lived in the past. It helps us understand why organisms look and behave the way they do. It provides a basis for exploring the relationships among different groups of living organisms.

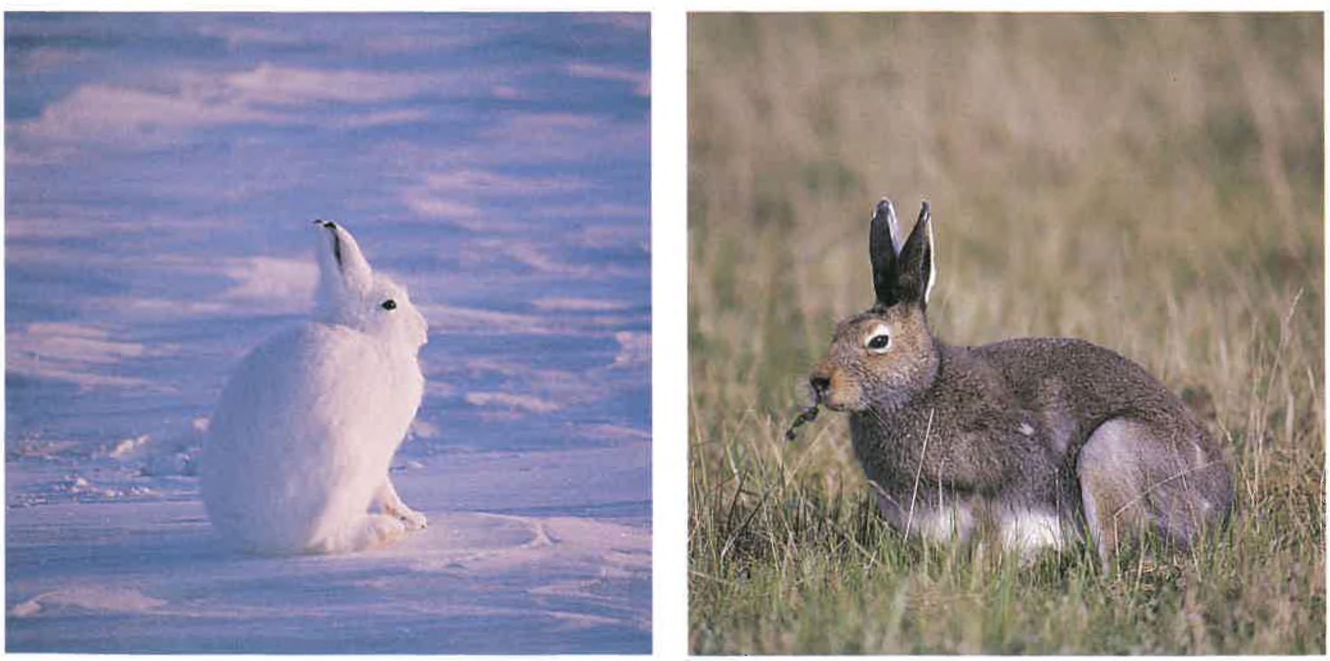
Scientists suggest that a process called **natural selection** is the most important driving force in evolution. According to the theory of evolution by natural selection, organisms that have certain favorable traits are better able to successfully reproduce than organisms that lack these traits. For example, white fur is helpful in snowy environments for animals like rabbits and mice, which are prey for many other species. Obviously, an animal that is killed early in life can produce no offspring at all. The animal in Figure 1-5 has a coat that changes color as the day length changes. Thus, it can retain its camouflage during winter and summer.

Evolution by natural selection is driven in part by the competition among individuals for resources necessary for survival, such as food. Not all individuals are able to live and reproduce to the same degree. Differences among individuals of a species can affect their ability to produce offspring. Some individuals have traits that give them advantages for survival and reproduction, and they tend to pass these traits on to their offspring.

The survival of organisms with favorable traits causes a gradual change in populations of organisms over many generations. This "descent with modification" as organisms adapted to different kinds of environments is responsible for the multitude of life-forms we see today.

FIGURE 1-5

Elegant solutions to the year-round problem of predation have evolved in some animals. The very different winter and summer coats of the arctic hare, *Lepus arcticus,* help the hare avoid predators.



Interdependence of Organisms

The study of individual organisms is an important part of biology. To fully understand the biological world, however, scientists study the interactions of organisms with one another and with their environment. This branch of biology is called **ecology.** A scientist may study the ecology of a single species. This would include observing individuals of the species and their interactions with each other and their environment. Scientists may also conduct large ecological studies of environments, studying specific **ecosystems** (EK-oh-SIS-tuhmz), or environmental communities. By studying ecology, biologists have come to recognize the interdependence of organisms with their physical environment. To survive, all organisms need substances such as nutrients, water, and gases from the environment. The stability of the environment in turn depends on the healthy functioning of organisms in that environment.

Scientists now recognize the enormous effect that humans have had on environments all over the world. For thousands of years, tropical rain forests, like the one shown in Figure 1-6, have provided stable—but fragile—environments for their inhabitants. In recent years, humans have cleared vast areas of these forests by cutting and burning vegetation. Roads cross areas that were once havens for tropical organisms. What is the effect of this activity? Plant and animal species native to the forest become extinct. The typically thin topsoil layer becomes depleted of nutrients and hardened by the sun. This makes the land unsuitable for planting or reestablishment of the forest. The atmospheric oxygen that was produced by the dense vegetation is lost. It is replaced by carbon dioxide from the burning of trees. Destruction of these ancient and valuable forests could affect all life on Earth.

Eco Connection

Saving the Forests

Tropical rain forests, like the one shown in Figure 1-6, exist at equatorial latitudes in Central and South America, Africa, and Asia. They are lush but extremely fragile multistoried ecosystems that support a staggering variety of life-forms. Before humans began cutting trees for timber and clearing land for farming, tropical rain forests covered about 6 million square miles on Earth. In the late 1970s, rain forests were being cleared at a rate of 29,000 square miles per year. By the early 1990s, that figure had climbed to more than 55,000 square miles per year. In less than 100 years, the rain forests may be gone.

Rain-forest products include rubber, coffee, and various kinds of fruits and nuts, as well as wood used for furniture, such as mahogany and teak, and wood used in paper manufacturing. Purchase by consumers of periodically harvested resources such as fruits, nuts, and rubber encourage responsible management of the rain forest renewable resources. Unfortunately, some paper manufacturers are very large-scale consumers of rain-forest wood. By learning about the track record of manufacturers with respect to rain-forest conservation, consumers can make more-responsible decisions about the products they use. Such awareness may help slow damage to these complex and irreplaceable ecosystems.

FIGURE 1-6

Tropical rain forests, like this one on the eastern slope of the Andes Mountains in Ecuador, support an extraordinary variety and number of plants and animals, typically on a very thin layer of fertile topsoil.

Matter, Energy, and Organization

Living things have highly organized structures that must be maintained in their orderly state by a constant supply of energy. How organisms obtain, use, and transfer energy is a major topic of study in biology. Almost all the energy for life on Earth comes from the sun. Through the process of **photosynthesis** (FOH-toh-SIN-thuh-sis), plants and some types of unicellular organisms capture the energy from the sun and change it into a form of energy that can be used by living things.

Word Roots and Origins

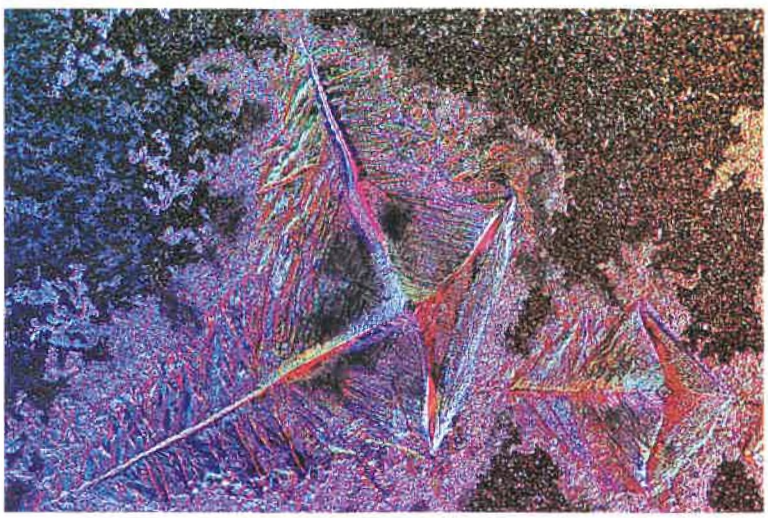
photosynthesis

from the Greek *photo,* meaning "light," and *syntithenai,* meaning "to put together"

Organisms that obtain their energy by making their own food, like plants, are called **autotrophs** (AWT-oh-TROHFS). Using the energy they trap from the sun, some kinds of autotrophs convert water and carbon dioxide from the environment into energy-rich substances such as sugars and starches. These substances are then used by the organisms for their own energy needs. Other kinds of autotrophs use different chemical processes to get energy. Autotrophs may be consumed and used as an energy source by other living things. **Heterotrophs** (HET-er-oh-TROHFS) are organisms that must take in food to meet their energy needs. Heterotrophs include all animals and fungi as well as many unicellular organisms and a few plant species. Because they cannot make their own food, heterotrophs must consume autotrophs, other heterotrophs, or both for their energy needs.

FIGURE 1-7

Many nonliving things, like this salt crystal (LM 55×), have a very organized structure but do not display the degree of organization and complexity found in living things.



In living things, complex chemicals are broken down. Their parts are then reassembled into chemicals and structures needed by the organism. Living things are set apart by their complexity. Even a simple, small organism, such as the alga shown in Figure 1-1, is far more complex than a nonliving thing, such as the mineral that appears in Figure 1-7. The mineral has an organized molecular and crystalline structure. However, the multitude of different molecular structures found in the alga are much more complex and varied than anything found outside the living world.

SECTION 1-1 REVIEW

1. List six unifying themes of biology.
2. How do organisms produce offspring like themselves?
3. What are two of the driving forces behind the process of natural selection?
4. Why are rain forests considered fragile environments that are vulnerable to permanent destruction?
5. How do autotrophs differ from heterotrophs in obtaining energy?
6. CRITICAL THINKING Why do scientists say that the environment "selects" the traits that allow an organism to survive and reproduce?

SECTION

1-2

THE WORLD OF BIOLOGY

Our world abounds with a great variety of life. Giant tube worms thrive at the bottom of the oceans near bubbling volcanic vents. Red algae spread to cover the surface of arctic glaciers like a carpet. Bacteria grow in every part of the world, even in the pores of your skin.

OBJECTIVES

▲ List six characteristics of life.

● Describe how a living thing is organized.

■ Explain why all living things on Earth are not yet well understood.

CHARACTERISTICS OF LIFE

All organisms, no matter how different from each other they may be, share certain features characteristic of all living things.

Cells

All living things are composed of cells. In multicellular organisms, some cells are specialized to play a specific role. The plant stem shown in Figure 1-8 contains many different cells, each separate from the surrounding cells, like many rooms in a large building. Cells are always very small. Large multicellular organisms contain many cells, while smaller organisms contain fewer cells.

Organization

All living things are highly organized at both the molecular and cellular levels. They take in substances from the environment and organize them in complex ways. In cells, specific cell structures carry out particular functions. In most kinds of multicellular organisms, cells and groups of cells are organized by their function. Several different cell types grouped together in the section of the plant stem are easily distinguished in Figure 1-8.

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FIGURE 1-8

The different types of cells in this plant stem are organized into structures that perform specific functions. The circular conducting tubes, shown in cross section (LM 19×), transport water and other substances up and down the plant stem.

FIGURE 1-9

All living things, even single cells, work to maintain a steady internal environment. Animals may have more than one mechanism that allows them to maintain a stable body temperature. This pine grosbeak, *Pinicola enucleator*, fluffs its feathers in cold weather to stay warm.

Energy Use

All living things use energy in a process called **metabolism** (muh-TAB-uh-LIZ-uhm), which is the sum of all of the chemical processes that occur in the organism. Organisms require energy to maintain their molecular and cellular organization as well as to grow and reproduce. Autotrophic organisms, such as green plants, use the food that they generate from photosynthesis for growth, maintenance, and reproduction.

Homeostasis

All living things maintain stable internal conditions. Even single cells work to keep their internal environment stable. A cell closely controls its water content by taking in or releasing water. A cell that takes in too much water will rupture and die. Multicellular organisms usually have more than one system for maintaining important aspects of their internal environment, like temperature. The feathers of the bird shown in Figure 1-9 become more erect in cold weather. This traps an insulating layer of air next to the bird's body.

Growth

All living things grow, as do many nonliving things. Nonliving things, like crystals or icicles, grow by accumulating more of the material they are made of. Living things grow as a result of cell division and cell enlargement. In unicellular organisms, cell division results in more organisms. **Cell division** is the formation of two cells from an existing cell, as shown in Figure 1-10. Newly divided cells enlarge until they are the size of a mature cell. In multicellular organisms, cell division and cell enlargement together result in growth.

The process by which an adult organism arises is called **development.** Development is produced by repeated cell divisions and cell differentiation. As a result of development, an adult organism is composed of many cells. Your body, for example, is composed of about 50 trillion cells, all of which derived from a fertilized egg.

Word Roots and Origins

metabolism

from the Greek *metabole,* meaning "to change"

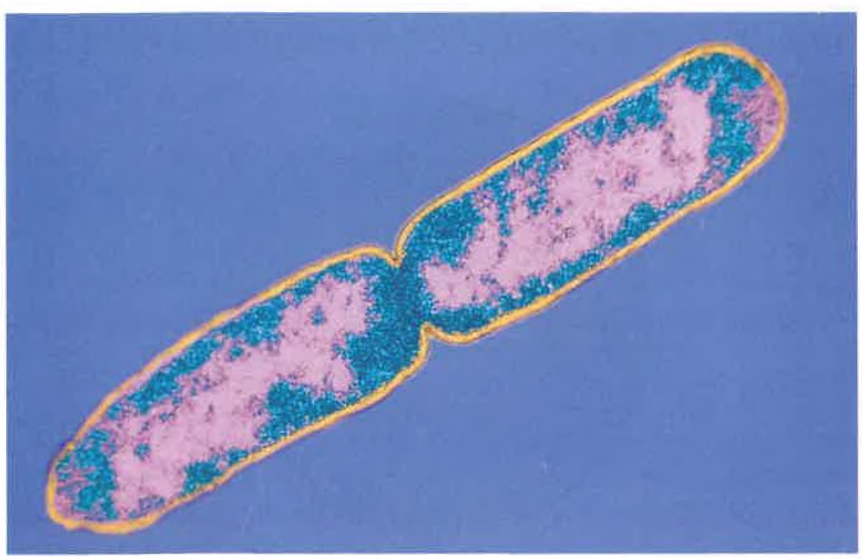

FIGURE 1-10

Cell division in this unicellular organism, *Escherichia coli* (TEM 98,000×), produces two identical offspring cells.

Reproduction

All species of organisms have the ability to reproduce. Reproduction is not essential to the survival of an individual organism. Because no organism lives forever, however, reproduction is essential for the continuation of a species. Glass frogs, such as the one shown in Figure 1-11, will lay many eggs in its lifetime. Of these, only a few offspring will reach adulthood and successfully reproduce.

During reproduction, many species have ways to combine the genetic information of individual members to produce offspring that are not identical to their parents. The frog shown in Figure 1-11 reproduces sexually. The eggs are fertilized by a male glass frog after they are laid. The resulting offspring carry traits of both parents. 4

FIGURE 1-11

Many species of animals that lay eggs produce large numbers of eggs. Many of the eggs laid by the glass frog, *Centrolenella* sp., will not survive. In contrast, the offspring of animals that give birth to live offspring typically have a high rate of survival.

THE LIVING WORLD

The world of biology is so diverse and so rich that scientists have yet to explore all of it. Many organisms that have not been identified live in regions of the world that are difficult to explore, like 5 dense tropical rain forests and deep ocean waters. Some organisms are so small that they easily escape detection. A single gram of fertile soil, for example, may contain as many as 2.5 billion unicellular organisms. In the dense forests of Vietnam, scientists recently discovered a new species of deer. It weighs between 40 and 50 kg (90 and 110 lb). It is one and a half times as large as any other known Asian deer species.

The wide variety of unstudied organisms shows us how much is still to be learned about life. Wherever you live, the world around you teems with life. This book will help you appreciate the living world and understand how scientists go about exploring and studying it.

SECTION 1-2 REVIEW

1. Name six characteristics that all living things share.
2. What are two levels of organization found in living things?
3. How does growth of a nonliving thing differ from growth of a living thing?
4. Why is reproduction an important characteristic of life?
5. Why are so many organisms yet to be discovered, identified, and described?
6. **CRITICAL THINKING** What would happen if all autotrophic organisms died, leaving only heterotrophic organisms?

SECTION

1-3

OBJECTIVES

▲ Define and give examples of *observing, measuring, organizing and analyzing data, inferring,* and *modeling.*

● Explain the relationship between hypothesizing, predicting, and experimenting.

■ Explain why good communication is so important in science.

◆ Describe the methods that scientists use in their work.

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SCIENTIFIC METHODS

One of the best ways to begin studying science is to examine how scientists try to solve a problem or answer a question. Whatever they study, all scientists use certain methods to obtain knowledge. Understanding scientific methods will help you formulate strategies to answer questions you will encounter in your own scientific study or in your daily life. Consider how scientists searched for the cause of one of the deadliest infectious diseases in humans—Ebola hemorrhagic fever.

OBSERVING

In 1976, a deadly and contagious human disease appeared in several villages in the central African nation of the Democratic Republic of Congo, then known as Zaire. Local doctors observed a rapidly progressing and consistent sequence of symptoms in disease victims. Most had severe headaches, fever, bloody diarrhea, and vomiting. In the final stages of the disease, victims' internal organs bled uncontrollably and blood leaked through the nose, ears, and even the skin. Death from shock—collapse of the cardiovascular system due to loss of blood—followed rapidly. Teams of scientists from the the Centers for Disease Control and Prevention (CDC), the agency of the United States government responsible for monitoring diseases, and the World Health Organization (WHO) were sent to Zaire. Their job was to investigate the circumstances of this severe outbreak of what seemed to be a new disease.

ASKING A QUESTION

All scientific investigations begin with one or more questions. Think of the many questions that a scientist sent to investigate an outbreak of a disease would have. How is the disease transmitted among people? What caused the disease to appear suddenly in humans? How long after exposure to the agent of infection do the first symptoms of the disease occur? Do all victims die? The most fundamental question to be answered about the outbreak of a new disease is *What is the disease-causing agent?*

COLLECTING DATA

The longest phase of a scientific investigation is usually data collection. **Data** include any and all information that scientists gather in trying to answer their questions. Four important aspects of collecting data are described in the following paragraphs.

Word Roots and Origins

data

the plural of datum; remains unchanged from the Latin *datum,* meaning "a thing given"

Observing

All scientific understanding of the natural world is based on observation. It is the observation of something unusual or unexplained that raises the first questions in a scientific investigation. Observation continues to be essential throughout all stages of scientific investigation. **Observation** typically employs one or more of the five senses to perceive objects or events. A scientist may observe the sound of the call of an animal in the wild. He or she may observe the appearance of an organism under a microscope, as the scientist is doing in Figure 1-12. Most observations in a scientific investigation are direct, although some things, like electricity, must be observed indirectly.

Measuring

Many kinds of observations involve quantitative data—data that can be measured in numbers. Scientists may measure the dimensions of an object, the number of objects in a group, the duration of an event, or other characteristics in precise units.

For example, in Zaire, the scientists recorded several types of quantitative data from their work in the field. These data included the number of people who displayed symptoms of the disease, the number of days that elapsed from the time symptoms first appeared until a victim died, and the number of people who died from the disease after they were infected. These data gave scientists a picture of the outbreak—an indication of how serious the disease was. The numbers they recorded revealed a grim picture. The outbreak had caused nearly 300 deaths. Death usually followed within a week after the first symptoms appeared, and the disease was extremely deadly. From 80 to 90 percent of the people who became infected died from the disease.

FIGURE 1-12

Scientists make many of their observations within the confines of a laboratory.

FIGURE 1-13

Because of its threadlike structure, the Ebola virus (TEM 23,000×) is classified as a filovirus. *Filo-* is a prefix meaning "threadlike" and is derived from the Latin word *filum,* which means "thread."

Sampling

Scientific **sampling** is the technique of using a sample, that is, a small part, to represent an entire population. To be useful, samples must be large and random. That is, they should include as many subjects as possible, and scientists must be sure to sample a cross section of the population so that an accurate representation is obtained. The scientists working in Zaire took hundreds of blood samples, both from people stricken with the disease and from people who were apparently healthy.

These blood samples taken from the disease victims provided the first important clue to the nature of the disease. The samples were sent from Zaire to laboratories in Europe and to the CDC in Atlanta, Georgia. Scientists at the CDC and at the University of Anvers, in Belgium, isolated a strange, threadlike virus from the blood samples. Using a powerful electron microscope, the scientists at the CDC photographed the virus, shown in Figure 1-13.

Organizing Data

Data are of little use unless they are organized. Organizing data involves placing observations and measurements in some kind of logical order, such as in a graph, chart, table, or map. The scientists tracking Ebola fever organized many kinds of data. They organized quantitative data into tables and charts. Remember that these quantitative data gave them an initial picture of how deadly the disease was.

Another important goal of the scientists was to trace the identity of the first person who had become infected with the disease. This information would be an important clue for identifying where the virus came from and how it was transmitted to humans. To do this, scientists who track the spread of a disease may organize information on all reported cases of the disease into a flowchart. The scientists can then trace the thread of contagious spread backward in hopes of identifying the first infected person. A flowchart, similar to the one shown in Figure 1-14, serves as a "family history" of the disease.

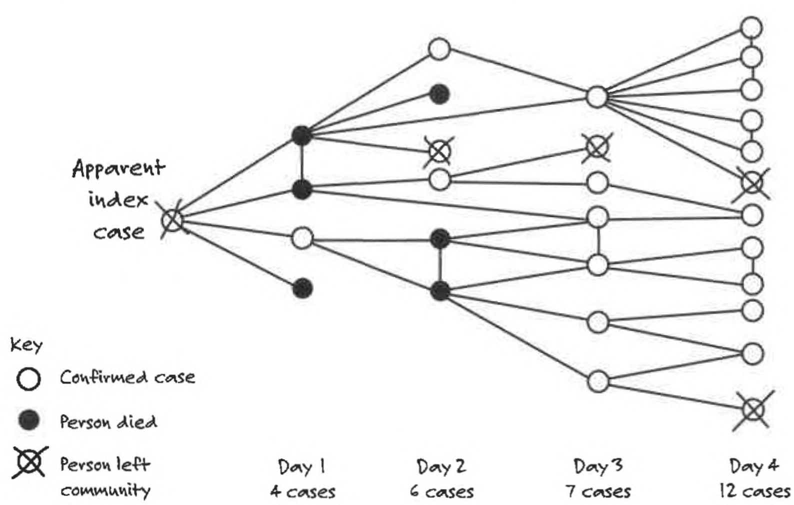


FIGURE 1-14

Scientists who trace the transmission of disease develop flowcharts much like this one so they can track the disease back to its source.

HYPOTHESIZING

When scientists have made many observations and collected sufficient data, they can suggest an explanation for what they have seen and recorded. This explanation, called a **hypothesis,** is a statement that explains their observations *and* can be tested.

Forming a Hypothesis

The central hypothesis in this complicated investigation was that the virus photographed by the CDC scientists caused the hemorrhagic fever. Although it may seem obvious that this is true, cause-and-effect relationships never can be assumed in a scientific investigation. Rather, evidence must be accumulated in every step.

Hypothesizing is a very important step in scientific investigation. A statement is testable if evidence can be collected that either does or does not support it. Recall the scientists' hypothesis about the identity of the infectious agent. It would not be supported if the infection with the virus did not cause symptoms of the disease.

Although a hypothesis may be supported by evidence, it can never be proved true beyond all doubt. At any time, new data might indicate that a previously accepted hypothesis does not hold true in all instances. Scientists often must refine and revise their original hypotheses—or even discard them—as they uncover new evidence.

Predicting

To test a hypothesis, scientists make a prediction that logically follows from the hypothesis. A **prediction** is a statement made in advance that states the results that will be obtained from testing a hypothesis, if the hypothesis is supported. A prediction most often takes the form of an "if-then" statement. In the case of Ebola fever, scientists made a prediction. If the virus were the true disease-causing agent, then introducing the virus into healthy tissue would cause cell death like that found in victims of the disease.

EXPERIMENTING

A hypothesis is often tested by carrying out an **experiment.** Experimenting is the process of testing a hypothesis or prediction by gathering data under controlled conditions.

Conducting a Controlled Experiment

Most experiments in biology are controlled experiments. A **controlled experiment** is based on a comparison of a **control group** with an **experimental group.** The control group and the experimental group are designed to be identical except for one factor. This factor is called the **independent variable.** During the course of a controlled experiment, a scientist observes or measures another factor in both the control group and the experimental group. This factor is called the **dependent variable**—dependent because it is driven by or results from the independent variable.

A controlled experiment supported the hypothesis that Ebola fever was caused by the previously unknown virus that was isolated by scientists in Belgium and the United States. Scientists at the University of Anvers tried to confirm the link between the virus and the cell death that caused the symptoms of the disease. Because monkeys are genetically similar to humans, kidney cells from a species of African monkey were used in an animal model of human infection. Test tubes containing the monkey kidney cells were divided into an experimental group and a control group. Drops of blood that contained the virus, taken from a victim of Ebola fever in Zaire, were added to each test tube in the experimental group. No blood was added to the test tubes in the control group. In the experiment, the independent variable was the addition of blood to the monkey kidney cells. The dependent variable was the health of the cells.

Analyzing Data

After a scientist has collected and organized data from a field study or an experiment, the data must be analyzed. Analyzing data is the process of determining whether data are reliable and whether they support or do not support a hypothesis or prediction. Scientists analyze data in many ways. For example, they may use statistics to determine relationships between variables, compare the data with those obtained in other studies, and determine possible sources of experimental error.

Eleven days after the virus-containing blood was mixed with the monkey kidney cells, the cells in the experimental test tube were dead. Moreover, addition of liquid from the experimental test tubes to new test tubes containing healthy monkey kidney cells caused the death of those cells also, again after a period of 10 to 11 days.

Quick Lab

Predicting Results

Materials 2 Petri dishes with agar, cellophane tape, wax pen

Procedure

1. Open one of the Petri dishes, and streak your finger across the surface of the agar.
2. Replace the lid, and seal it with cellophane tape. Label this Petri dish with your name and the number 1.
3. Seal the second Petri dish without removing the lid. Label this Petri dish with your name and the number 2.
4. Record a description of your actions for each Petri dish. Then write your prediction about what will happen in each dish.
5. Store your dishes as your teacher directs.
6. Record your observations.

Analysis

1. Was your prediction accurate? What evidence can you cite to support your prediction?
2. If you did not obtain the results you predicted, would you change your testing method or your prediction? Explain why and how you would make changes.
3. Evaluate the importance of obtaining a result that does not support your prediction.

DRAWING CONCLUSIONS

The goal of scientific investigation is to shed light on something previously not understood. The final step of most investigations is to produce a model.

Modeling

Modeling involves constructing a representation of an object, a system, or a process that helps show relationships among data. A **model** is essentially an *explanation* supported by data. It can be visual, verbal, or mathematical. Scientists sometimes use models to help generate new hypotheses or predictions. For example, scientists have examined the case histories of people who have died from Ebola fever to develop a model of how the virus is transmitted among humans. Close contact with an infected person is necessary. Direct contact with the blood of an infected person seems to be the likeliest way to become infected. Many people who had Ebola fever were infected in crowded hospitals, like the one shown in Figure 1-15, by contaminated needles and instruments. Scientists are not sure whether the virus can penetrate skin or enter through the nose or mouth. Perhaps a break must first be present in the skin or lining of the nose or mouth.

The model of Ebola virus transmission is far from complete. The first human case in the 1976 outbreak in Zaire was never identified. Scientists still do not know the identity of the animal species that harbors the virus in the wild or how the virus is spread to humans. Once scientists have developed a complete model of where the virus originates and how it is transmitted to humans, they can specify the precautions to take to avoid infection.

FIGURE 1-15

The Ebola virus spread in hospitals and clinics in Zaire because of overcrowded and unsanitary conditions.

Inferring

An **inference** (IN-fuhr-uhns) is a conclusion made on the basis of facts or premises rather than on direct observations. If you see smoke, you will probably infer that its source is a fire, even if you can't see the fire. In science, inferences are often drawn from data gathered from a field study or experiment, considered together with previous knowledge. Unlike a hypothesis, an inference is not directly testable. The scientists on the trail of the source of the Ebola virus made several important inferences from their work.

For example, based on the observations they made and the data they collected and analyzed, scientists inferred that the Ebola virus is carried by a small, forest-dwelling animal, possibly a bat. The virus may not cause the disease-carrying animals, or hosts, to become ill, as it does to humans. Scientists suspect that the host animals periodically move in search of food into regions inhabited or used by humans. When they do, they come in contact with people, some of whom contract the virus from the animals.

Forming a Theory

In science, a theory may be formed after many related hypotheses have been tested and supported with much experimental evidence. The word *theory* does not mean "wild guess"; it does not even mean "hypothesis." Rather, a **theory** is a broad and comprehensive statement of what is thought to be true. A theory is supported by considerable evidence and may tie together several related hypotheses. Few true theories are produced in science, relative to the volume of work performed and the number of hypotheses tested.

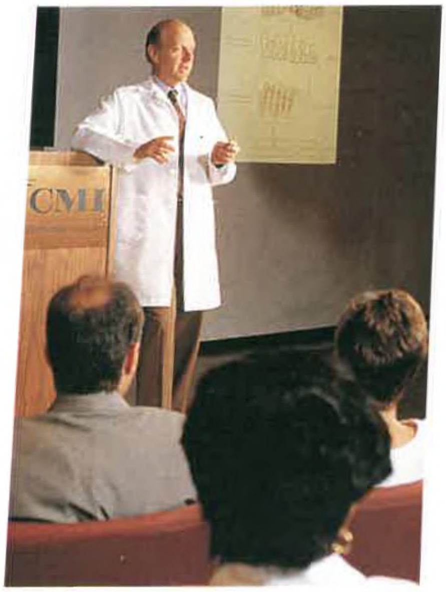


FIGURE 1-16

Throughout the world, scientists often gather to share what they have discovered. Each gathering is usually devoted to a specific subject or topic.

IMPLEMENTING SCIENTIFIC METHODS

In real-life situations, scientists do not follow one single method of asking questions and seeking answers. Instead, scientists combine some of the processes of the scientific methods in a way that is best suited to answer the questions they ask.

Problem Solving

A field biologist might wish to investigate the animal source of Ebola fever in the rain forest. He or she might use scientific methods that combine observing, hypothesizing, sampling, organizing data, and analyzing data. Consider a laboratory biologist working to understand how the Ebola virus attacks body cells. He or she might use scientific methods that combine observing, measuring, organizing data, hypothesizing, predicting, experimenting, analyzing data, and constructing a model. A public health official would likely be concerned about the spread of Ebola fever in a population. He or she might use scientific methods that combine organizing data, analyzing data, predicting, and inferring.

Communicating

As you have seen in the case of Ebola fever, scientists do not work alone. They share the results of their studies with other scientists. They publish their findings in scientific journals or present them at scientific meetings, like the one shown in Figure 1-16. Sharing information is essential to progress in science. The work of every scientist is subject to examination and verification by other scientists. Communication allows scientists to build on the work of others. Recall that communication among scientists throughout the world enabled them to isolate the Ebola virus. The same kind of communication enabled scientists to recognize the outbreaks of Ebola fever that occurred in Zaire in 1995 and Gabon in 1996. Health-care workers responded much sooner than they had in the earlier outbreaks. Though many people died, a far worse epidemic was avoided thanks to good communication and cooperation among scientists and health-care workers.

SECTION 1-3 REVIEW

1. How are the processes of inferring and modeling useful to scientists?
2. What is the relationship between hypothesizing and experimenting in science?
3. What role does communication play in science?
4. Explain why there is no single scientific method.
5. How does a theory differ from a hypothesis?
6. **CRITICAL THINKING** "Science rarely develops absolute truths that apply to all living things." Based on what you have read about scientific processes, do you think this statement is true?

SECTION

1-4

OBJECTIVES

Compare light microscopes with electron microscopes in terms of magnification and resolution.

Explain the advantage of the Système International d'Unités.

MICROSCOPY AND MEASUREMENT

To study the living world, biologists need to observe cells and their parts. The development of new tools and new techniques enables biologists to probe even deeper into life's secrets.

MICROSCOPES

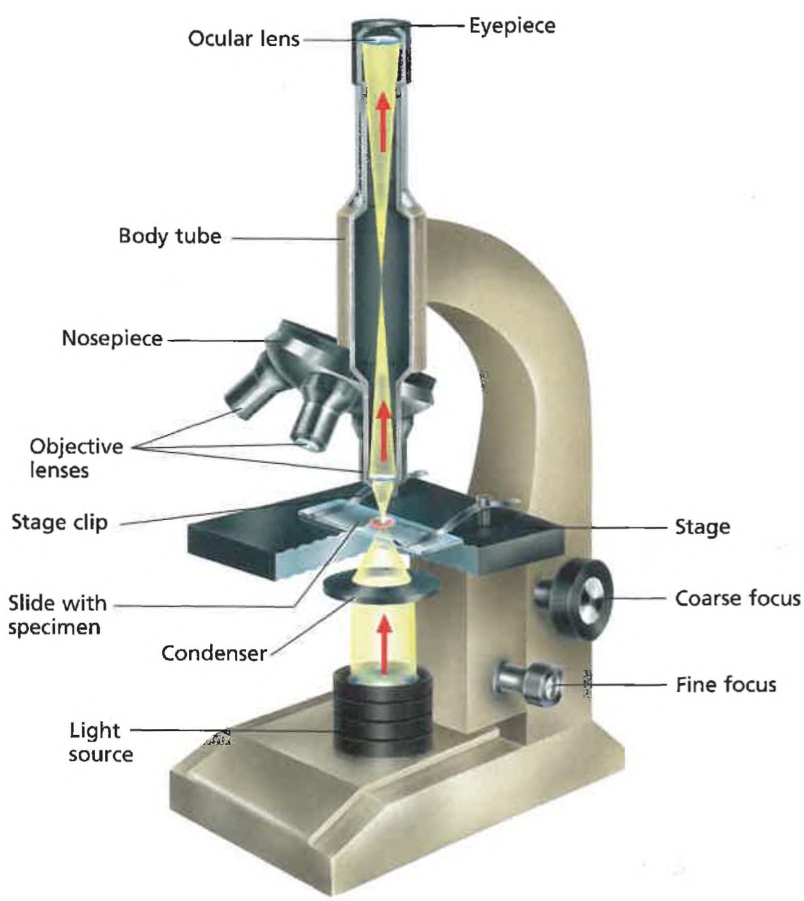
Among the most widely used tools in biology are microscopes. A **microscope** is an instrument that produces an enlarged image of an object. Biologists use microscopes to study organisms, cells, and cell parts that are too small to otherwise be seen. Microscopes both enlarge the image made by an object and show its details. The increase of an object's apparent size is **magnification.** The power to show details clearly refers to **resolution** (REZ-uh-LU-shuhn). Microscopes vary in powers of magnification and resolution.

Light Microscopes

To see small organisms and cells, biologists typically use a **compound light microscope (LM),** as shown in Figure 1-17. To be viewed with a compound light microscope, a specimen is mounted on a glass slide. The specimen must be sliced thin enough to be transparent, or it must be very small. The slide holding the specimen is placed over the opening in the **stage** of the microscope. A light source, a light bulb or mirror in the base, directs light upward. Light passes through the specimen and through the **objective lens,** which is positioned directly above the specimen. The objective lens enlarges the image of the specimen. This magnified image is projected up through the body tube to the **ocular** (AHK-yoo-luhr) **lens** in the eyepiece, where it is magnified further.

FIGURE 1-17

In a compound light microscope, the image of a transparent specimen is enlarged as it passes through the objective and ocular lenses.



Word Roots and Origins

magnification

from the Latin *magnificus/magnus*, meaning "large" or "great"

Most light microscopes have a set of objective lenses with different powers of magnification. These lenses can be rotated into place by revolving the **nosepiece.** In a typical compound light microscope, the most powerful objective lens produces an image 40 times the actual size of the specimen. This factor of enlargement is called the **power of magnification** of the lens, and it is represented, in this case, as 40×. The standard ocular lens magnifies a specimen 10 times (10×). To compute the power of magnification of a microscope, the power of magnification of the strongest objective lens (in this case 40×) is multiplied by the power of magnification of the ocular lens (10×). This results in a total power of magnification of 400×.

Electron Microscopes

The resolution power of light microscopes is limited by the physical characteristics of light. At powers of magnification beyond about 2,000×, the image of the specimen becomes blurry. To examine specimens even smaller than cells, such as cell parts or viruses, scientists may choose from several types of electron microscopes. In an **electron microscope,** a beam of electrons—rather than a beam of light—produces an enlarged image of the specimen. Electron microscopes are much more powerful than light microscopes. Some electron microscopes can even show the contours of individual atoms in a specimen.

The **transmission electron microscope,** called a TEM, transmits a beam of electrons through a very thinly sliced specimen. Magnetic lenses enlarge the image and focus it on a screen or photographic plate. This produces an image like the one shown in Figure 1-18a. Transmission electron microscopes can magnify objects up to 200,000 times. But TEMs do have an important limitation—they cannot be used to view living specimens.

The **scanning electron microscope,** called an SEM, provides striking three-dimensional images, as you can see in Figure 1-18b. Specimens are not sliced for viewing. Rather, the surface of the specimen is sprayed with a fine metal coating. A beam of electrons is passed over the specimen's surface. This causes the metal coating to emit a shower of electrons. These electrons are projected onto a fluorescent screen or photographic plate, producing an image of the surface of the object. Scanning electron microscopes can magnify objects up to 100,000 times, and like the TEM, they cannot be used to view living specimens.

FIGURE 1-18

This unicellular organism, *Giardia lamblia*, looks very different when viewed by (a) transmission electron microscopy and (b) scanning electron microscopy.

(a)

(b)

MEASUREMENT

Scientists use a single, standard system of measurement. The official name of the measurement system is Système International d'Unités (International System of Measurements), or simply **SI.** You will use the same units when you make measurements in the laboratory.

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Base Units

There are seven fundamental **base units** in SI that describe length, mass, time, and other quantities, as shown in Table 1-1. Multiples of a base unit (in powers of 10) are designated by prefixes, as shown in Table 1-2. For example, the base unit for length is the meter. One *kilo*meter is equal in length to 1,000 meters.

TABLE 1-1 ***SI Base Units***

Base quantity	Name	Abbreviation
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

TABLE 1-2 ***Some SI Prefixes***

Prefix	Abbreviation	Factor of base unit
giga	G	1,000,000,000
mega	M	1,000,000
kilo	k	1,000
hecto	h	100
deka	da	10
deci	d	0.1
centi	c	0.01
milli	m	0.001
micro	μ	0.000001
nano	n	0.000000001
pico	p	0.000000000001

TABLE 1-3 SI Derived Units Often Used in Biology

Derived quantity	Name	Abbreviation
Area	square meter	m^2
Volume	cubic meter	m^3
Mass density	kilogram per cubic meter	kg/m^3
Specific volume	cubic meter per kilogram	m^3/kg
Celsius temperature	degree Celsius	°C

TABLE 1-4 Other Units Acceptable for Use with SI

Name	Abbreviation	Value in SI units
Minute	min	1 min = 60 s
Hour	h	1 h = 60 min = 3,600 s
Day	d	1 d = 24 h = 86,400 s
Liter	L	1 L = 1 dm^3 = 0.001 m^3
Metric ton	t	1 t = 1,000 kg

Derived Units

The base units in Table 1-1 cannot be used to measure surface area or velocity, among other things. Therefore, other important units, derived units, are used. **Derived units** are produced by the mathematical relationship between two base units or between two derived units. Table 1-3 shows some common derived units.

Other Units

Some units of measurement that are not part of the SI are accepted for use with SI units. They are units of time, volume, and mass, as shown in Table 1-4.

SECTION 1-4 REVIEW

1. How do microscopes differ in magnification and resolution?
2. How is the maximum power of magnification computed for a compound light microscope?
3. How does a scanning electron microscope work?
4. How does a transmission electron microscope work?
5. If SI measurement is no more accurate than the English system, why do scientists throughout the world use it?
6. CRITICAL THINKING Why might a scientist prefer to use the lower powers of a light microscope to observe aspects of unicellular organisms?

CHAPTER 1 REVIEW

SUMMARY/VOCABULARY

1-1

- Biology is the study of life, ranging from the study of unicellular organisms to the study of the global interactions among millions of organisms.
- Six themes serve to unify the study of biology: (1) cell structure and function; (2) stability and homeostasis; (3) reproduction and inheritance; (4) evolution; (5) interdependence of organisms; and (6) matter, energy, and organization.
- The cell is the basic unit of life. Organisms may be unicellular or multicellular.
- Living things maintain a stable level of internal conditions, called homeostasis.
- Reproduction involves the transmission of hereditary information from organisms to their offspring.
- Populations of organisms evolve over generations primarily by a process called natural selection.
- Organisms interact in important ways with each other and with their environments.
- Living things have highly organized structures that are maintained by a constant input of energy.
- Autotrophs obtain energy by making their own nutrients.
- Heterotrophs obtain energy from the nutrients they obtain from their environment.

Vocabulary

asexual reproduction (7)
autotroph (10)
biology (5)
differentiation (6)
DNA (7)
ecology (9)
ecosystem (9)
evolution (8)
evolve (8)
gene (7)
heterotroph (10)
homeostasis (6)
multicellular organism (6)
natural selection (8)
organism (5)
photosynthesis (10)
reproduction (7)
sexual reproduction (7)
unicellular organism (6)

1-2

- Living things are composed of cells.
- Living things are more highly organized than nonliving structures.
- Living things use energy in a process called metabolism.
- Living things have several mechanisms that help them maintain stable internal conditions.
- When living things grow, their cells enlarge and divide.
- Living things reproduce, producing offspring similar to themselves.
- There is a great deal yet to be learned about the living world.

Vocabulary

cell division (12)
development (12)
metabolism (12)

1-3

- Scientific investigations generally begin with observation.
- Methods scientists use in their work include (1) observing, (2) asking a question, (3) collecting data, (4) hypothesizing, (5) experimenting, and (6) drawing conclusions.
- A hypothesis is a statement that explains observations *and* that can be tested.
- In a controlled experiment, the experimental group is identical to the control group except for one factor called the independent variable.
- Communication is very important in science because scientists build on the work of others.

Vocabulary

control group (17)
controlled experiment (17)
data (15)
dependent variable (18)
experiment (17)
experimental group (17)
hypothesis (17)
independent variable (18)
inference (19)
model (18)
observation (15)
prediction (17)
sampling (16)
theory (19)

1-4

- Biologists often use a compound light microscope to see small things, like cells.
- Electron microscopes provide higher magnification and better resolution than do light microscopes.
- Système international d'unités (SI) is a standard system of measurement that uses seven fundamental base units.
- All measurements scientists make are done using SI units, derived units, and other acceptable units.

Vocabulary

base unit (23)
compound light microscope (21)
derived unit (24)
electron microscope (22)
magnification (21)
microscope (21)
nosepiece (22)
objective lens (21)
ocular lens (21)
power of magnification (22)
resolution (21)
scanning electron microscope (SEM) (22)
SI (23)
stage (21)
transmission electron microscope (22)

REVIEW

Vocabulary

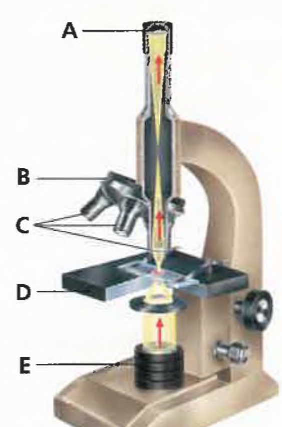
1. What is the difference between asexual reproduction and sexual reproduction?
2. Compare heterotrophs with autotrophs.
3. How do cell division and enlargement contribute to growth?
4. Explain the difference between formulating a model and inferring.
5. Describe the similarities and differences between a transmission electron microscope and a scanning electron microscope.

Multiple Choice

6. Reproduction involves the transfer of genetic information from (a) autotroph to heterotroph (b) parents to offspring (c) offspring to parents (d) unicellular organism to multicellular organism.
7. The theory of evolution by natural selection helps explain how complex organisms came into existence, why organisms of the past differ from those alive today, and how various groups of living organisms (a) develop (b) reproduce (c) obtain energy (d) are related to each other.
8. The hereditary material in living things is (a) CDC (b) thyroid hormone (c) carbon dioxide (d) DNA.
9. Organisms that obtain energy by taking in food are called (a) autotrophs (b) heterotrophs (c) homeostatic (d) reproducers.
10. Growth occurs by (a) organization and reproduction (b) adaptation and evolution (c) inferring and adapting (d) cell division and cell enlargement.
11. The combination of genetic information from two individuals occurs during (a) homeostasis (b) development (c) reproduction (d) differentiation.
12. The most important driving force in evolution is (a) cellular organization (b) differentiation (c) natural selection (d) development.
13. Data that are quantitative are always (a) described in words (b) represented by numbers (c) recorded on a tape recorder (d) seen through a microscope.
14. A hypothesis is a statement that (a) is identical to a theory (b) can be tested (c) is usually true (d) is always true.
15. The resolution of a microscope refers to (a) its power to increase an object's apparent size (b) its ability to show detail clearly (c) its series of interchangeable objective lenses (d) its power to scan the surface of an object.

Short Answer

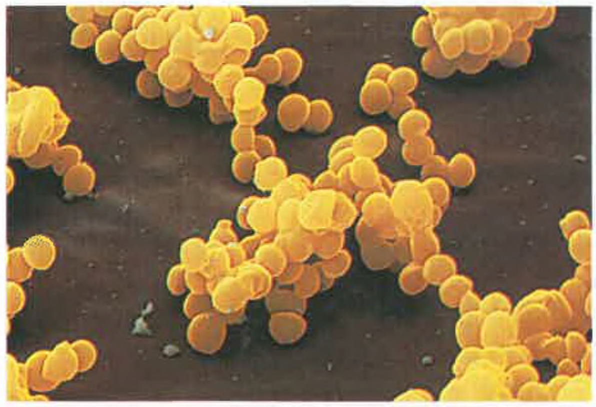
16. Name the part of the compound light microscope denoted by each letter.

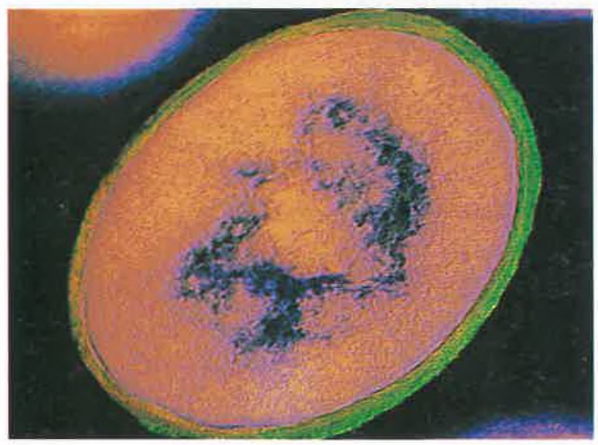


17. Why do biologists say that living things are organized?
18. What are the different results produced by cellular division in a unicellular organism and in a multicellular organism?
19. Explain how the process of natural selection can change traits over time.
20. What is an ecosystem?
21. Why have some animals only recently been discovered?
22. What is the relationship between a hypothesis and a prediction?
23. Describe a controlled experiment that was conducted to confirm the cause of Ebola fever.
24. What is a model?
25. What is an important limitation of SEMs and TEMs in observing organisms?

CRITICAL THINKING

1. One of the first branches of biology to be developed was taxonomy, the naming of organisms. Why is taxonomy important to communication about biology?
2. Rock crystals grow and become larger. How does this process differ from the way living things grow?
3. 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?
4. Scientists know that a disease-causing organism can cause overwhelming illness or death very quickly. Why would it not be adaptive for a disease-causing organism to kill its victims too quickly?
5. Look at the photographs below. The SEM, top, is of *Staphylococcus aureus*. The TEM, bottom, is also of *S. aureus*. Compare and contrast what each electron micrograph tells you about this organism.





EXTENSION

1. Read the chapter titled "Project Ebola" in Richard Preston's book *The Hot Zone*. The chapter describes the outbreak of the Ebola virus in the Reston, Virginia, primate research facility in 1989. Answer the following questions: Why was the research on Ebola virus done in a Level 4 area? Why was negative air pressure used in the lab? What special precautions did the scientists have to take before entering the Level 4 area?
2. Using a compound light microscope, observe prepared slides of unicellular organisms such as *Euglena* under three different powers of magnification. Draw a picture of each organism as it appears at each power of magnification, and write a brief description of the level of detail that you see.

CHAPTER 1 INVESTIGATION

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.

PROCESS SKILLS

- measuring
- calculating

MATERIALS

- 75 mL light-colored sand
- 75 mL dark-colored sand
- 1100 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

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.
3. Level the sand by placing the cup on your desk and sliding the cup back and forth.

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		

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 below left. Make sure the lamp is evenly positioned between the two containers.
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**

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 actual 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:

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

14. To find the mass of the 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:

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

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

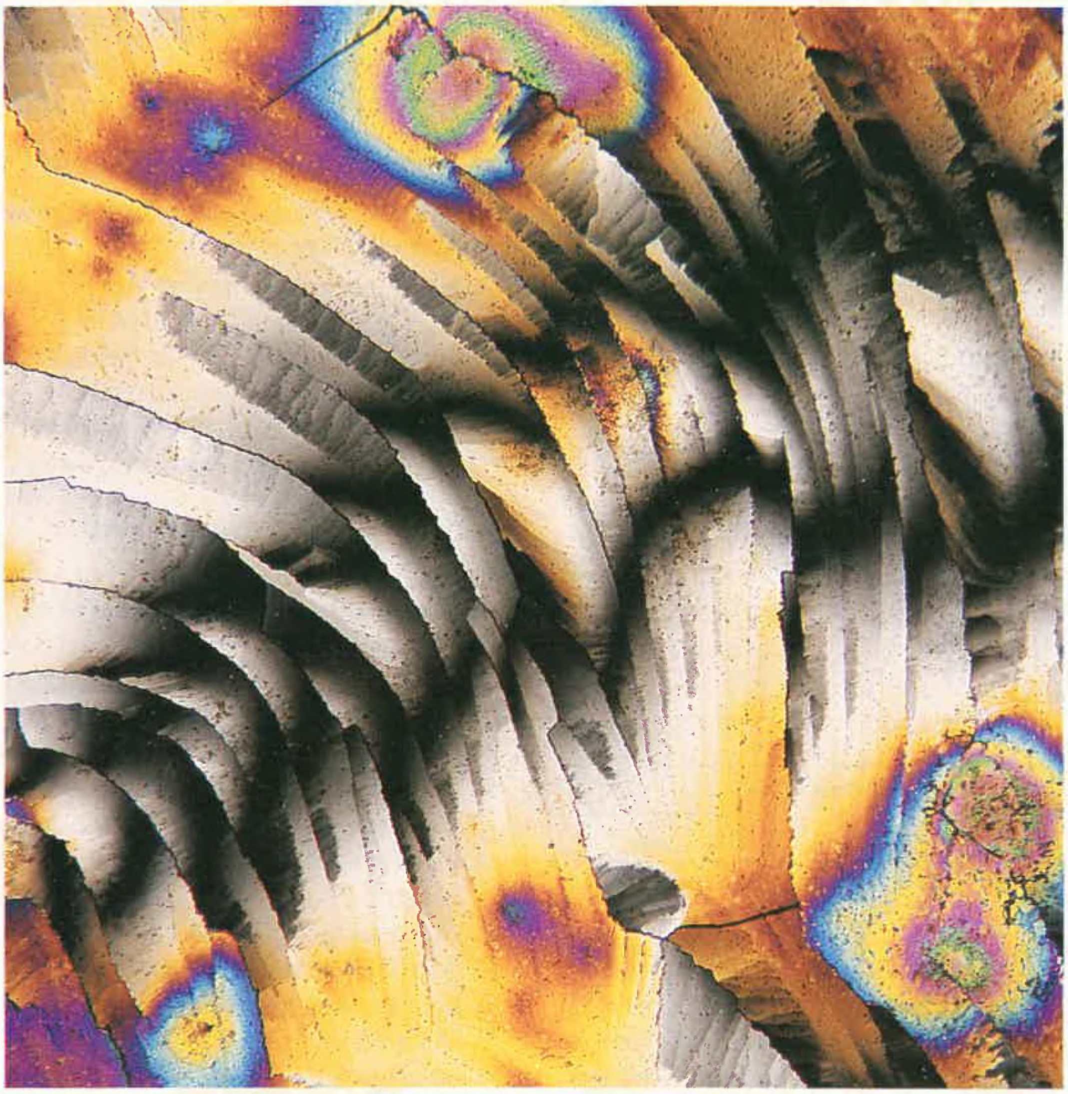
1. Graph the data you collected in Part A. Plot time on the *x*-axis and temperature on the *y*-axis.
2. Based on your data from Part A, what is the relationship between color and heat absorption?
3. How might the color of the clothes you wear affect how warm you are on a sunny 90° day?
4. In Part B, what did you observe when you combined the oil and water in the clear cup? Relate your observation to the densities that you calculated for the two liquids.
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



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

FOCUS CONCEPT: ***Matter, Energy, and Organization***

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

Composition of Matter

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

SECTION

2-1

OBJECTIVES

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

● Draw a model of the structure of an atom.

■ Explain what determines an atom's stability.

◆ Contrast ionic and covalent bonds.

MATTER

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

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

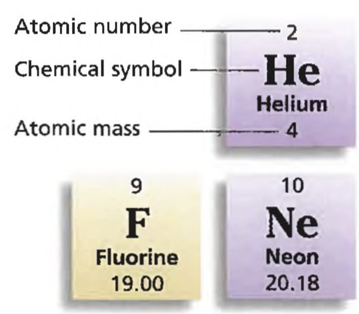
ELEMENTS

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

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

FIGURE 2-1

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



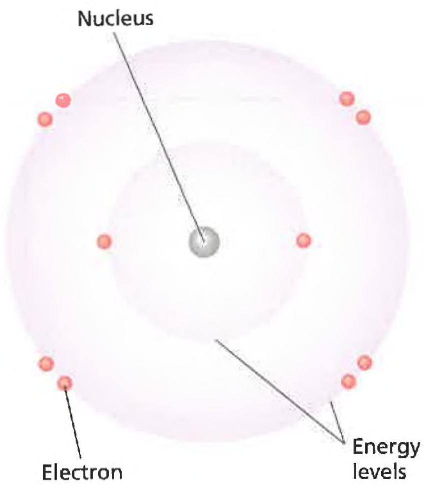


FIGURE 2-2

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

ATOMS

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

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

The Nucleus

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

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

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

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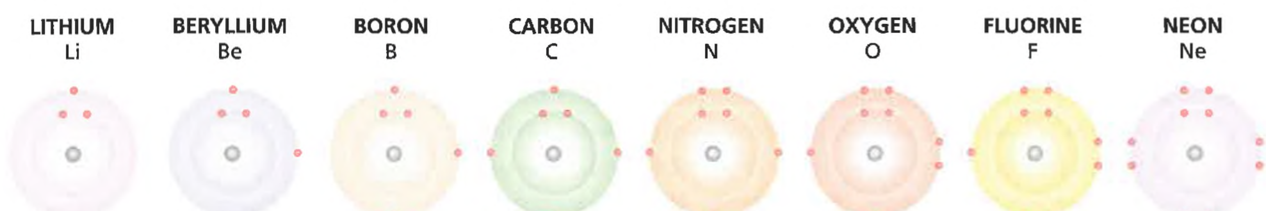
Electrons

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

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

FIGURE 2-3

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



COMPOUNDS

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

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

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

Covalent Bonds

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

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

Word Roots and Origins

compound

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

FIGURE 2-4

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

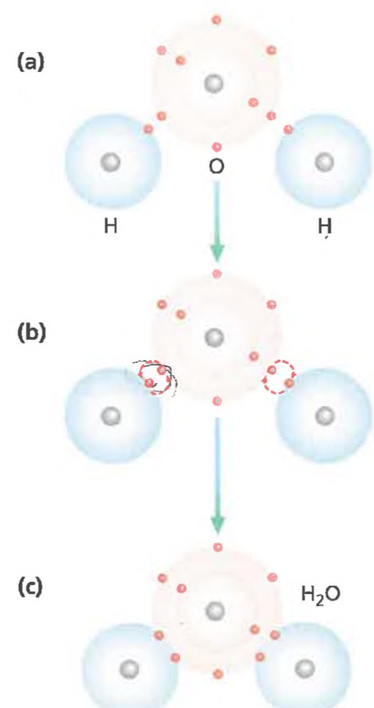
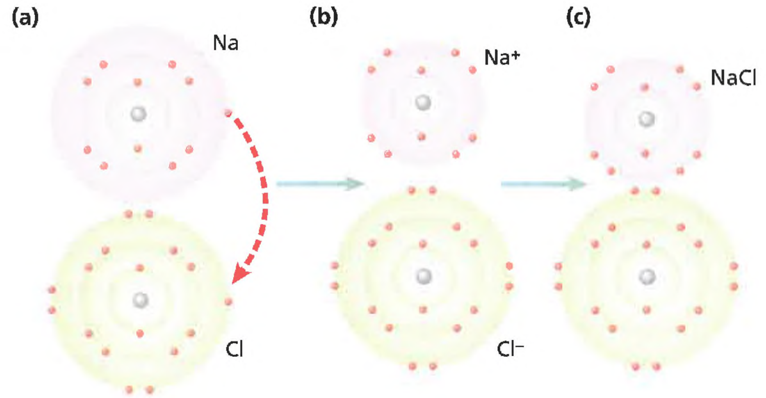


FIGURE 2-5

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



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Ionic Bonds

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

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

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

SECTION 2-1 REVIEW

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

SECTION

2-2

ENERGY

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

ENERGY AND MATTER

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

Energy in Living Things

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

States of Matter

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

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

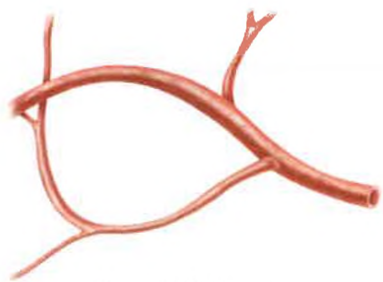
OBJECTIVES

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

● Describe how energy changes are involved in chemical reactions.

■ Explain how enzymes affect chemical reactions in organisms.

◆ Explain what a redox reaction is.



$CO_2 + H_2O \rightleftharpoons H_2CO_3$

FIGURE 2-7

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

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

ENERGY AND CHEMICAL REACTIONS

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

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

Energy Transfer

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

Activation Energy

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

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

Word Roots and Origins

catalyst

from the Greek *katalysis,* meaning "dissolution"

Activation Energy With and Without a Catalyst

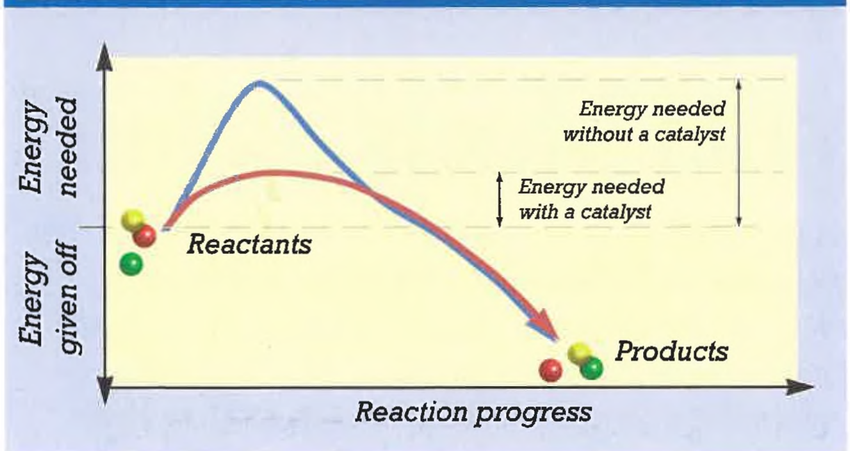


FIGURE 2-8

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

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

Reduction-Oxidation Reactions

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

Quick Lab

Modeling Ionic Bonds

Materials toothpicks, mini marshmallows, peas

Procedure

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

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

SECTION 2-2 REVIEW

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

GREAT DISCOVERIES

Blood Plasma Meets a Need

HISTORICAL PERSPECTIVE

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

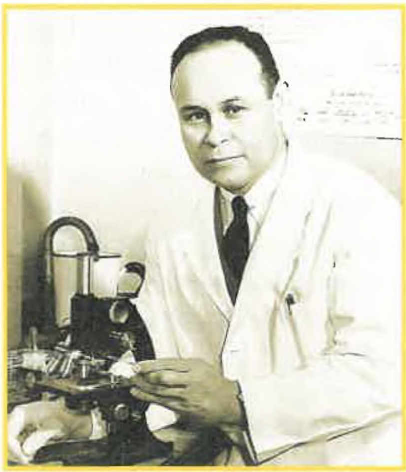
The Need

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

Historical Highlights

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

The early 1900s marked a breakthrough. The Austrian-born American physiologist Karl Landsteiner determined that there are four blood types—A, B, AB, and O—based on the compatibility of markers on the outer surface of red blood cells. Landsteiner's



Charles Drew

discovery explained why the outcome of transfusions had been so unpredictable. For his work, Landsteiner received the Nobel Prize in medicine or physiology in 1930.

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

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

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

The Composition of Blood

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

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

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

Response to Wartime Needs

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

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

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

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

Transfusion Update

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

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

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

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

SECTION

2-3

OBJECTIVES

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

● Explain the dissociation of water.

■ Contrast properties of acids and bases.

◆ Describe the use of the pH scale.

◆ Explain the action of buffers.

SOLUTIONS

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

DESCRIBING SOLUTIONS

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

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

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

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 say *acid* and *alkaline*?

Dissociation of Water

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

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

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

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

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

Acids

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

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

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

FIGURE 2-9

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

Eco Connection

Acid Precipitation

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

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

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

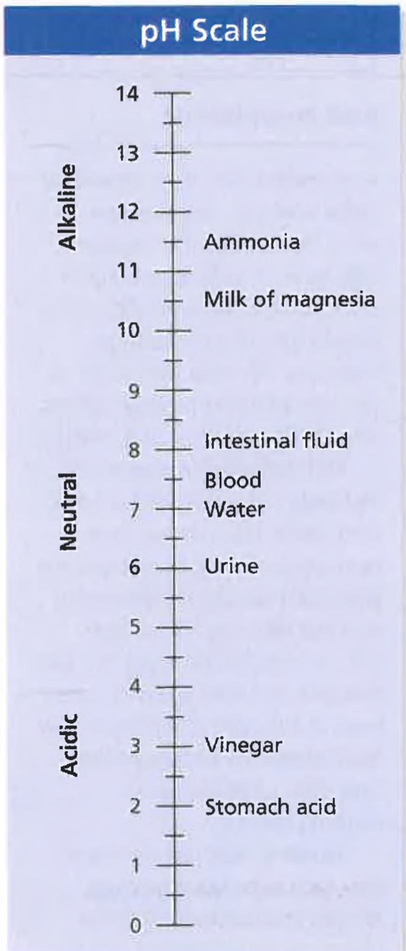


FIGURE 2-10

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

Bases

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

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

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

pH

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

Buffers

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

SECTION 2-3 REVIEW

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

CHAPTER 2 REVIEW

SUMMARY/VOCABULARY

2-1

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

Vocabulary

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

2-2

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

Vocabulary

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

2-3

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

Vocabulary

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

REVIEW

Vocabulary

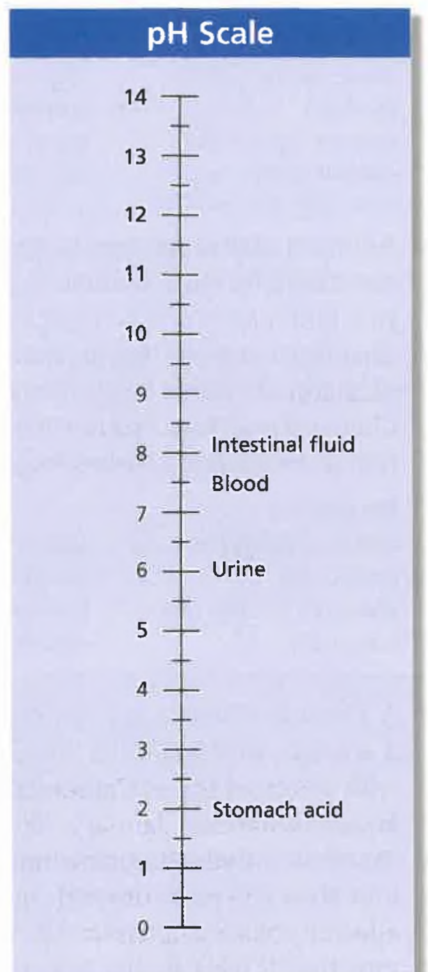
1. Explain the relationship between electrons, neutrons, and protons.
2. What is the difference between an element and a compound?
3. Distinguish the differences in composition between an acid and a base.
4. Identify the type of reaction that releases free energy.
5. How are the processes of oxidation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

Multiple Choice

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

Short Answer

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



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

CRITICAL THINKING

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

Melting and Boiling Points at Normal Pressure

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

EXTENSION

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

CHAPTER 2

INTERACTIVE EXPLORATION

Exploring the Activity of Biological Catalysts

OBJECTIVES

- Simulate the effect of pH, temperature, and enzyme concentration on the activity of two enzymes.
- Determine the optimal conditions for each enzyme.

MATERIALS

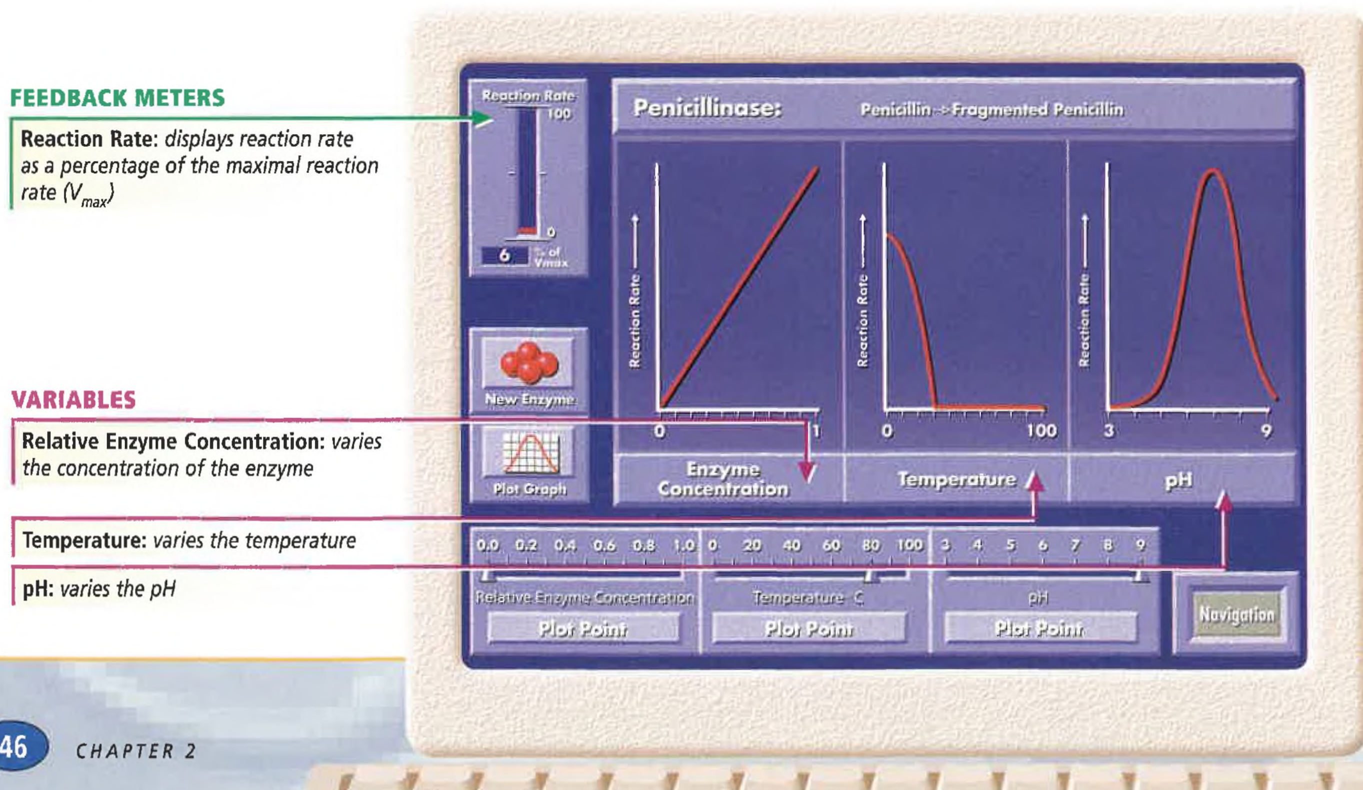
- computer with CD-ROM drive
- CD-ROM *Interactive Explorations in Biology: Cell Biology and Genetics*
- graph paper

Background

All organisms rely on enzymes to catalyze chemical reactions. Recall that an enzyme is a biological catalyst that increases the rate of a chemical reaction by lowering the level of activation energy necessary to start the reaction. Without enzymes, many of the chemical reactions that occur within living things would proceed too slowly to be useful. Enzymes speed up these reactions by bringing the reactants into close proximity and facilitating their interaction. Enzyme effectiveness depends on several factors. This interactive investigation allows you to explore how three of these factors—enzyme concentration, temperature, and pH—affect the activity of two enzymes present in the human body, carbonic anhydrase and lysozyme. Carbonic anhydrase helps regulate carbon dioxide levels in red blood cells. Lysozyme breaks large sugar molecules into smaller ones during metabolism.

Prelab Preparation

1. Load and start the program Thermodynamics. You will see an animated diagram like the one below. Click the Navigation button, and then click the Topic Information button with the "key" icon on it. Read the focus questions, and review the following concepts: Reaction Rate, Enzyme Catalysis, Temperature and Reaction Rates, and pH Can Influence Enzyme Shape.
2. Click the word *Help* at the top left of the screen, and select How to Use This Exploration. Listen to the instructions for conducting the exploration. Click the Interactive Exploration button on the Navigation Palette to begin the exploration.



Procedure

PART A Carbonic Anhydrase Activity

1. Click the New Enzyme button until "Carbonic Anhydrase" appears at the top of the screen.
2. Click and drag the indicator so that the Relative Enzyme Concentration is 0.2.
3. Click the Plot Point button. The point that appears on the graph indicates the rate of reaction for this enzyme concentration, expressed as a percentage of V_{max}, the highest possible reaction rate. What is the reaction rate indicated by the Reaction Rate meter?
4. Repeat steps 2 and 3 until you have tested the following relative enzyme concentrations: 0.4, 0.6, 0.8, and 1.0.
5. Click the Plot Graph button. How does increasing the enzyme concentration affect the rate of reaction?
6. Make a table similar to Table A shown below.

TABLE A EFFECTS OF TEMPERATURE ON REACTION RATE

Temperature	Carbonic anhydrase % of V_{max}	Lysozyme % of V_{max}
0°C		
10°C		
20°C		
30°C		
40°C		
50°C		

7. Click and drag the indicator so that the Temperature meter indicates 0°C. Click the Plot Point button, and observe the result. In your table, record the reaction rate.
8. Repeat step 7 until you have tested the effects of the following temperatures: 10°C, 20°C, 30°C, 40°C, and 50°C.
9. Use graph paper to make a graph of temperature versus reaction rate. Draw a curve that connects your six points. What can you conclude about the effect of temperature on the activity of carbonic anhydrase?
10. Click the Plot Graph button. Compare your graph with the one shown on the screen. Explain any differences.

TABLE B EFFECTS OF pH ON REACTION RATE

pH	Carbonic anhydrase % of V_{max}	Lysozyme % of V_{max}
3		
4		
5		
6		
7		
8		

11. Make a table similar to Table B shown above.
12. Click and drag the indicator so that the pH meter indicates a pH of 3. Click the Plot Point button, and observe the result. In your table, record the reaction rate.
13. Repeat step 12 until you have tested the following pH values: 4, 5, 6, 7, and 8.
14. After testing all the values above, make a graph of pH versus reaction rate. Draw a curve that connects your points. What can you conclude about the effect of pH on the activity of carbonic anhydrase?
15. Click the Plot Graph button. Compare your graph with the graph on the screen. Explain any differences.

PART B Lysozyme Activity

16. Click the New Enzyme button until "Lysozyme" appears at the top of the screen.
17. Repeat steps 2–15 for the enzyme lysozyme, completing Table A and Table B.

Analysis and Conclusions

1. What is the optimal temperature for each enzyme? What is the optimal pH for each enzyme?
2. The optimal pH of pepsin, a stomach enzyme, is about 2, while the optimal pH of trypsin, an enzyme of the small intestine, is about 8. What must occur in your digestive tract between the stomach and the small intestine?

CHAPTER 3

BIOCHEMISTRY

The body of this jellyfish, Pseudorhiza haeckeli, *is almost 99 percent water.*

FOCUS CONCEPT: *Matter, Energy, and Organization*

As you read this chapter, notice how function depends on structure in each of the compounds you examine.

SECTION

3-1

OBJECTIVES

Describe the structure of a water molecule.

Explain how water's polar nature affects its ability to dissolve substances.

List two of water's properties that result from hydrogen bonding.

WATER

Compare the body of the jellyfish shown on the opposite page with your own body. The jellyfish will die if it is removed from its water environment. You can live in the driest parts of Earth. Jellyfish and humans seem utterly unlike each other, yet the bodies of both are made of cells filled with water. The chemical reactions of all living things take place in an aqueous environment. Water has several unique properties that make it one of the most important compounds found in living things.

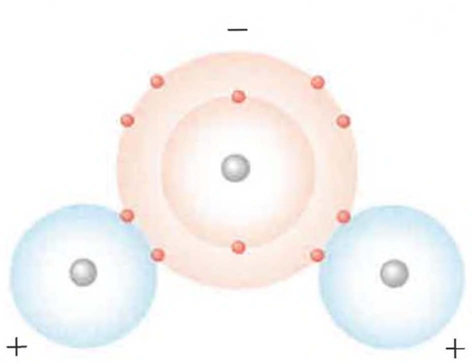
POLARITY

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. An oxygen atom has eight protons in its nucleus and therefore eight positive charges to attract electrons, whereas a hydrogen atom has only one proton and therefore one positive charge. With its greater positive charge, the nucleus of the oxygen atom pulls the shared electrons toward its nucleus and away from the nucleus of the hydrogen atom. As a result, the electrical charge is unevenly distributed, as shown in the models of a water molecule shown in Figure 3-1.

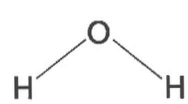
Notice too in Figure 3-1 that the three atoms in a water molecule are not arranged in a straight line as you might expect. Rather, the two hydrogen atoms bond with the single oxygen atom at an angle. Although the total electrical charge on a water molecule is neutral, the region of the molecule where the oxygen atom is located has a

FIGURE 3-1

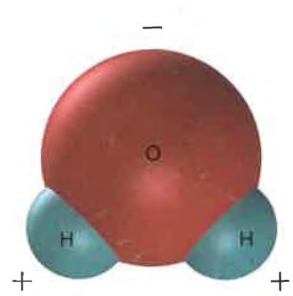
The oxygen region of the water molecule is weakly negative, and the hydrogen regions are weakly positive. Notice the three very different ways to represent water, H_2O. You are familiar with the electron-energy-level model (a) from Chapter 2. The structural formula (b) is compact and easy to understand. The space-filling model (c) shows the three-dimensional structure of a molecule.



(a) Electron-energy-level model



(b) Structural formula



(c) Space-filling model

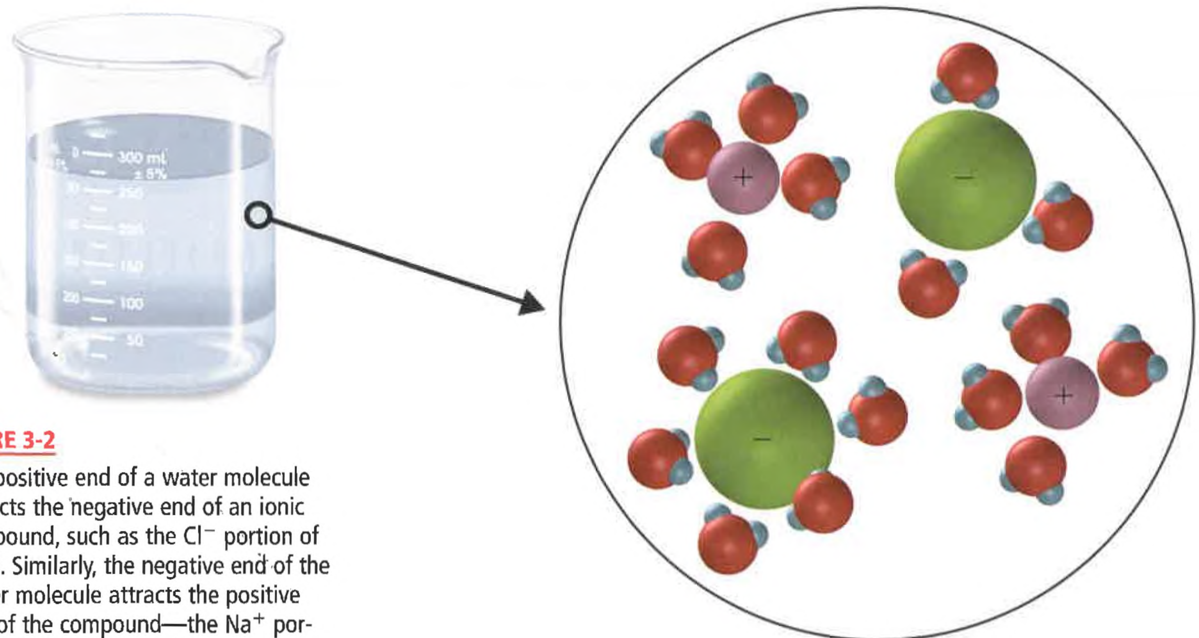
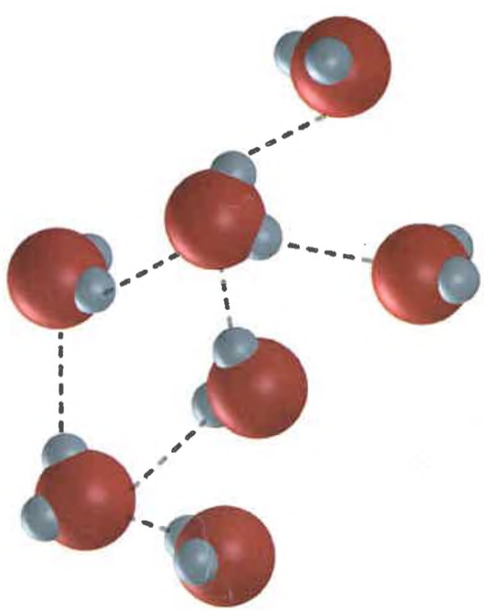


FIGURE 3-2
The positive end of a water molecule attracts the negative end of an ionic compound, such as the Cl^- portion of NaCl. Similarly, the negative end of the water molecule attracts the positive end of the compound—the Na^+ portion of NaCl. As a result, NaCl breaks apart, or dissociates, in water.

slightly negative charge, while the regions of the molecule where each of the two hydrogen atoms are located have a slightly positive charge. Because of this uneven pattern of charge, water is called a **polar** compound.

It is this polar nature that makes water very effective in dissolving many other substances. Water dissolves other polar substances, including sugars and some proteins, as well as ionic compounds, such as sodium chloride, NaCl. An ionic compound mixed with water tends to dissociate into ions. This is illustrated in Figure 3-2. This breaking up of an ionic compound frees ions to participate in many biological reactions. In your body, both sodium ions and chloride ions are essential to functions like muscle contraction and transmission of impulses in the nervous system. In fact, dissolved, dissociated ions are present in all of the aqueous solutions found in living things. Their concentration is critical to the normal operation of the many systems of your body.

FIGURE 3-3
The dotted lines in this figure represent hydrogen bonds. A hydrogen bond is a weak force of attraction between a hydrogen atom in one molecule and a negatively charged atom in a second molecule.



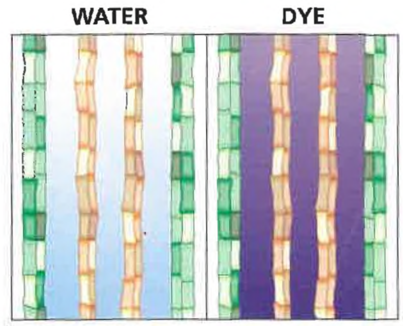
HYDROGEN BONDING

The polar nature of water also causes water molecules to be attracted to one another. The type of attraction that holds two water molecules together is called a **hydrogen bond.** As shown in Figure 3-3, a positive region of one water molecule is attracted to the negative region of another water molecule. Thus, a hydrogen bond tends to form between a hydrogen atom in one molecule and the region of negative charge on another molecule. A hydrogen bond is a weak bond that can be easily broken. Even so, the hydrogen bonds in water exert a significant attractive force, causing water to cling to itself and to other substances.

Cohesion and Adhesion

An attractive force between particles of the same kind is known as **cohesion.** You can see cohesion at work when you observe the surface tension of water. Cohesive forces resulting from water's hydrogen bonding are strong enough to cause water to act as if it has a thin "skin" on its surface. This is why water appears to bulge from the sides of a glass filled to the brim.

Adhesion is the attractive force between unlike sustances. Together, adhesion and cohesion enable water molecules to #5 move upward through narrow tubes against the force of gravity. This property of water is known as **capillarity** (KAP-uh-LER-it-ee). You have seen capillarity at work if you have observed the flow of water into a flower through its stem, such as is shown in Figure 3-4.



Liquid movement up a stem

FIGURE 3-4

Because of strong cohesive and adhesive forces, water can travel upward from the roots of flowers. In the flower on the right, the water, which has been dyed blue, has moved up through the stem to the flower's petals.

Temperature Moderation

Water must gain or lose a relatively large amount of energy for its temperature to change. When water is heated, most of the thermal energy that the water initially absorbs breaks the hydrogen bonds between the molecules. Only after these bonds have been broken does the thermal energy increase the motion of the molecules and raise the temperature of the water. You read in Chapter 1 that all organisms must maintain homeostasis to live. In organisms, water's ability to absorb large amounts of energy helps keep cells at an even temperature despite temperature changes in the environment.

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TOPIC: Hydrogen bonding
GO TO: www.scilinks.org
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SECTION 3-1 REVIEW

1. Describe the structure of a water molecule.
2. How do molecules of a polar compound differ from those of a nonpolar compound?
3. What happens when ionic compounds are mixed with water?
4. What are two properties of water that result from water's tendency to form hydrogen bonds?
5. What is capillarity?
6. **CRITICAL THINKING** Most automobiles have water-cooled engines. What must be true about a solution that can replace water in the cooling system, such as antifreeze?

SECTION

3-2

OBJECTIVES

▲ Define *organic compound* and name three elements often found in organic compounds.

● Explain why carbon forms so many different compounds.

■ Define *functional group* and explain its significance.

◆ Compare a condensation reaction with hydrolysis.

CARBON COMPOUNDS

All of the many compounds discovered can be classified in two broad categories: organic compounds and inorganic compounds. ***Organic compounds*** *contain carbon atoms that are covalently bonded to other carbon atoms and to other elements as well—typically hydrogen, oxygen, and nitrogen. The chemistry of carbon is the chemistry of life.*

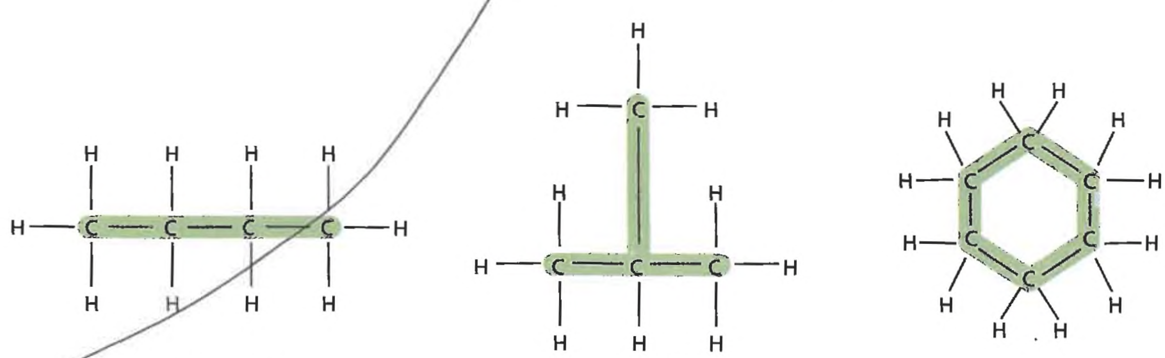
CARBON BONDING

A carbon atom has four electrons in its outermost energy level. Remember from Chapter 2 that most atoms become stable when their outermost energy level contains eight electrons. A carbon atom therefore readily forms four covalent bonds with 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 3-5. 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 3-5 represents a covalent bond formed when two atoms share a pair of electrons. A bond formed when two atoms share a pair of electrons is called a single bond. Carbon can also share two or even three pairs of electrons with another atom. Figure 3-6a 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 shown in Figure 3-6b.

FIGURE 3-5

Carbon can bond in a number of ways to produce molecules of very different shapes, including straight chains, branched chains, and rings. These structures form the backbone of many different kinds of organic molecules.



(a) Benzene (b) Acetylene (c) Ethanol

FIGURE 3-6

Carbon can form (a) double or even (b) triple bonds to satisfy its need for eight electrons in its outermost energy level. Organic molecules can have many different shapes and patterns of bonding. Organic molecules can also have many different functional groups, which influence the properties of the molecule they are attached to. Notice the hydroxyl, —OH, group on this model of the alcohol ethanol (c).

FUNCTIONAL GROUPS

In most organic compounds, clusters of atoms, called **functional groups,** influence the properties of the molecules they compose. The functional group is the structural building block that determines the characteristics of the compound. One functional group important to living things, the hydroxyl group, —OH, is shown in Figure 3-6c.

An **alcohol** is an organic compound with a hydroxyl group attached to one of its carbon atoms. Locate the hydroxyl group in the alcohol shown in Figure 3-6c. The hydroxyl group makes an alcohol a polar molecule. Thus, alcohols have some properties similar to water, including the ability to form hydrogen bonds. The alcohol illustrated in Figure 3-6c is ethanol, which is found in alcoholic beverages. Ethanol causes cell death in the liver and brain of humans. The alcohol methanol, also called wood alcohol, can cause blindness or even death when consumed. Some alcohols, however, are needed by organisms to carry out their life processes. Humans, for example, need the alcohol glycerol to assemble certain molecules necessary for life.

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

Analysis How does this activity demonstrate polarity of molecules that contain the –OH group?

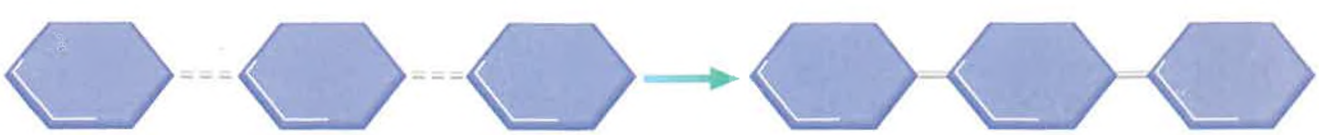
LARGE CARBON MOLECULES

In many carbon compounds, the molecules are built up from smaller, simpler molecules known as **monomers,** such as the ones shown in Figure 3-7. As you can also see in Figure 3-7, monomers can bond to one another to form complex molecules known as polymers. A **polymer** consists of repeated, linked units. The units may be identical or structurally related to each other. Large polymers are called **macromolecules.**

Monomers link to form polymers through a chemical reaction called a **condensation reaction.** In the condensation reaction shown

FIGURE 3-7

A polymer is the result of bonding between monomers. The six-sided shape is an organic structural model of a molecule with a central carbon ring. The organic structure of a molecule shows the arrangement of carbon atoms in organic molecules.



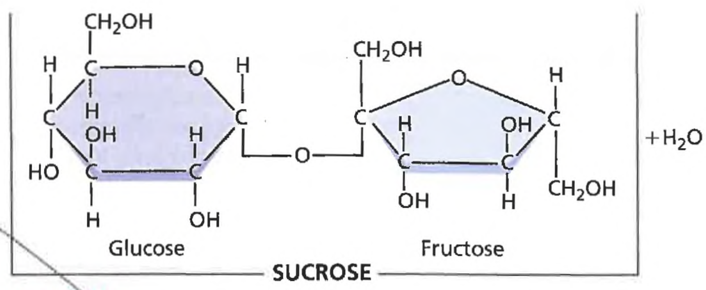


FIGURE 3-8

The condensation reaction of one glucose molecule with one fructose molecule yields sucrose and water. One water molecule is produced each time two monomers form a covalent bond.

in Figure 3-8, 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 hydroxide ion, OH^-, and the fructose molecule releases a hydrogen ion, H^+. The OH^- and H^+ ions that are released in turn combine to produce a water molecule, H_2O.

The breakdown of some complex molecules, such as polymers, occurs through a process known as **hydrolysis** (HIE-DRAH-luh-sis). Hydrolysis is a reversal 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. As you can see in Figure 3-9, in hydrolysis a large molecule breaks apart.

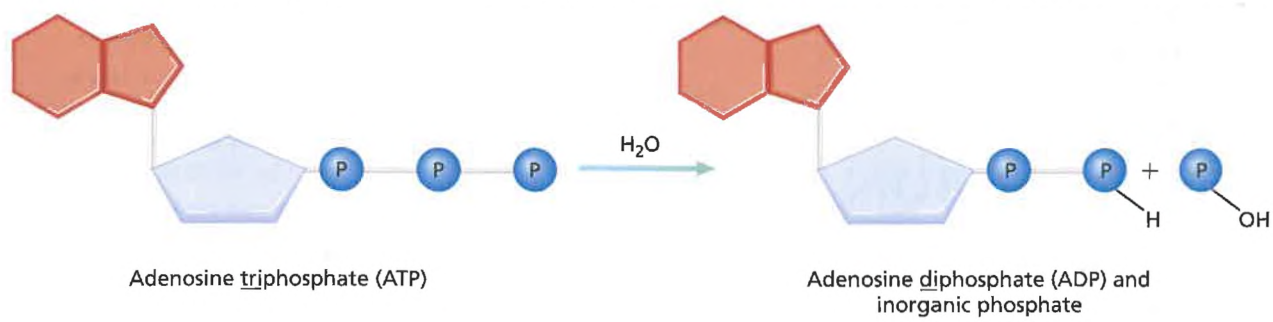
Energy Currency

Life processes require a constant supply of energy. This energy is available to cells in the form of certain compounds that contain 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.**

Figure 3-9 shows the structure of an ATP molecule. Notice the three linked phosphate groups, —PO_4^-, that are attached to one another by covalent bonds. The covalent bond that holds the last phosphate group to the rest of the molecule is easily broken. When this bond is broken, much more energy is released than was required to break the bond. This conversion of energy is used by the cell to drive the chemical reactions that enable an organism to function.

FIGURE 3-9

The hydrolysis of ATP yields adenosine diphosphate 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 are exergonic.



SECTION 3-2 REVIEW

1. What is an organic compound?
2. What property allows carbon compounds to exist in a number of forms?
3. Define *functional group* and give an example.
4. How does a polymer form?
5. How does a polymer break down?
6. **CRITICAL THINKING** Scientists can determine the age of a substance using a method that compares the amounts of different forms of carbon atoms present in the substance. Is this method more useful for organic substances or inorganic substances?

SECTION

3-3

OBJECTIVES

▲ Define *monosaccharide, disaccharide,* and *polysaccharide,* and discuss their significance to organisms.

● Relate the sequence of amino acids to the structure of proteins.

■ Relate the structure of lipids to their functions.

◆ List two essential functions of nucleic acids.

MOLECULES OF LIFE

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 from carbon, hydrogen, and oxygen, the atoms occur in different ratios in each class of compound. Despite their similarities, the different classes of compounds have different properties.

CARBOHYDRATES

Carbohydrates are organic compounds composed of carbon, hydrogen, and oxygen in a ratio of about two hydrogen atoms to one oxygen atom. The number of carbon atoms in a carbohydrate varies. Carbohydrates 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 3-10. 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 and is usually combined with glucose or fructose. Notice in Figure 3-10 that glucose, fructose, and galactose have the same molecular formula, $C_6H_{12}O_6$, but their differing structures determine the slightly different properties of the three compounds. Compounds like these sugars, with a single chemical formula but different forms, are called **isomers** (IE-soh-muhrz).

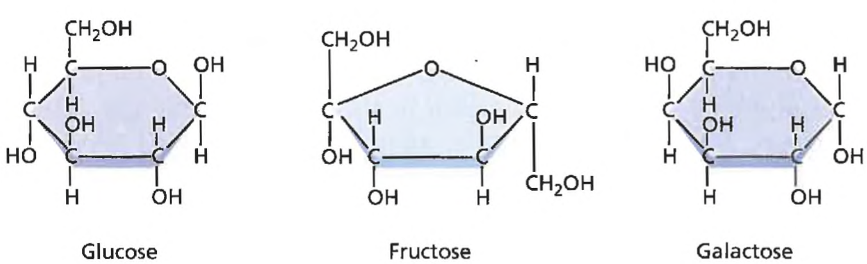


FIGURE 3-10

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

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KEYWORD: HM055

Disaccharides and Polysaccharides

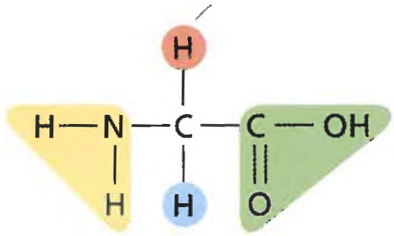
In living things, two monosaccharides can combine in a condensation reaction to form a double sugar, or **disaccharide.** As you saw in Figure 3-8, sucrose, which is common table sugar, is composed of fructose and glucose. A **polysaccharide** is a complex molecule composed of three or more monosaccharides.

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.

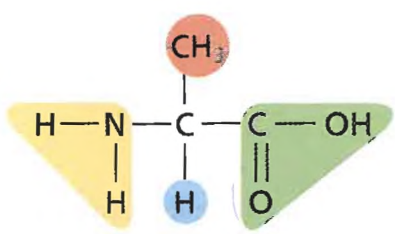
In plants, glucose molecules are linked in the polysaccharide starch. Starch molecules have two basic forms—highly branched chains that are similar to glycogen and long, unbranched chains that coil like a telephone cord. The large polysaccharide cellulose is also made by plants. Cellulose, which gives 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 3-11

Amino acids differ only in the type of R group (shown in red) they carry. Glycine (a) has a simpler R group than alanine (b). The R group may be either polar or nonpolar. Amino acids with polar R groups can dissolve in water, while those with nonpolar R groups cannot.



(a) Glycine



(b) Alanine

PROTEINS

Proteins are organic compounds composed mainly of carbon, hydrogen, oxygen, and nitrogen. Like the other macromolecules, proteins are formed from the linkage of monomers. The skin and muscles of animals are made mostly of proteins, as are many of the catalysts found in both plants and animals.

Amino Acids

The 20 different **amino acids,** the monomer building blocks of proteins, share a basic structure. As Figure 3-11 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 on 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. And a functional group call the R group, highlighted in red, bonds at the fourth site.

The main difference among the different amino acids is found in their R groups. The R group can be as simple as the single hydrogen atom of glycine, shown in Figure 3-11a, or it can be more complex, such as the R group shown in the model of alanine, shown in Figure 3-11b. The differences among the amino acid R groups gives different proteins very different shapes. The different shapes allow proteins to perform many different roles in the chemistry of living things.

Dipeptides and Polypeptides

Figure 3-12 shows how two amino acids bond to form a **dipeptide** (die-PEP-tied). In a condensation reaction, two amino acids form a covalent bond, called a **peptide bond.**

Amino acids can bond to each other one at a time, forming a very long chain called a **polypeptide** (PAH-lee-PEP-tied). 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—among individual amino acids. Protein shape can also be influenced by conditions such as temperature or the type of solvent in which a protein is dissolved. When you cook an egg, heat changes the shape of proteins in the egg white. The firm, opaque result is very different from the clear, runny material you began with.

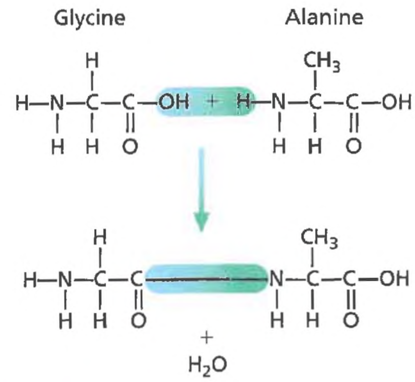


FIGURE 3-12

The peptide bond that binds amino acids together results from a condensation reaction that produces water.

Enzymes

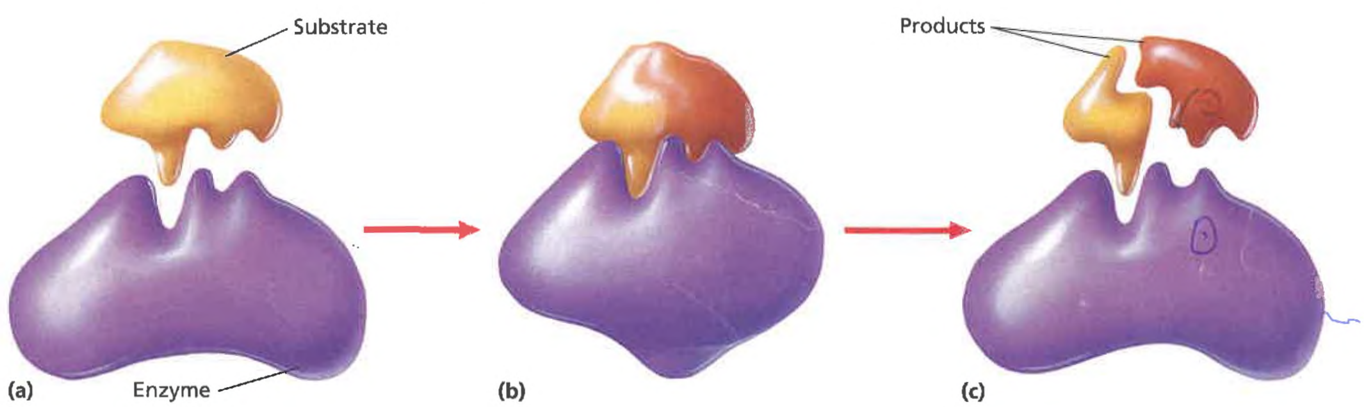
Remember from Chapter 2 that enzymes—organic molecules that act as catalysts—are essential for the functioning of any cell. Most enzymes are proteins.

Figure 3-13 shows a model of enzyme action. Enzyme reactions depend on a physical fit between the enzyme molecule and its **substrate,** the reactant being catalyzed. Notice in Figure 13-3a that the enzyme and substrate have shapes that allow them to fit together like a lock and key. The linkage of the enzyme and substrate causes a slight change in the enzyme's shape, shown in Figure 13-3b. This shape change allows the enzyme to conform to the shape of the substrate and probably weakens some chemical bonds in the substrate, which is one way that enzymes reduce activation energy. After the reaction, the enzyme releases the products, as shown in Figure 13-3c. Like any catalyst, the enzyme itself is unchanged, so it can be used many times.

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

FIGURE 3-13

(a) In the lock-and-key model of enzyme action, the enzyme can attach only to a reactant with a specific shape. (b) The enzyme then flexes to conform to the reactant's shape. (c) The enzyme is unchanged by the reaction it participates in and is released to be used again.



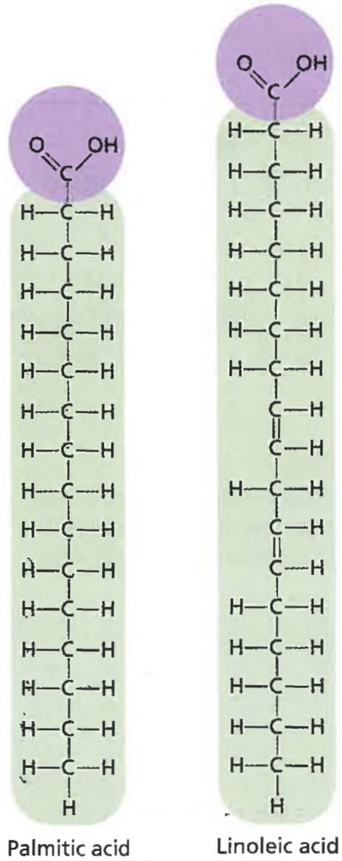
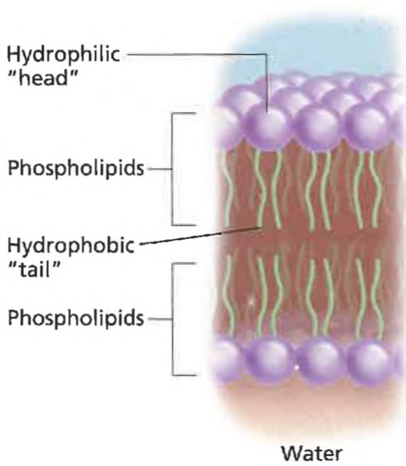


FIGURE 3-14

Fatty acids have a polar carboxyl head, purple, and a nonpolar hydrocarbon tail, green.

FIGURE 3-15

The lipid bilayer of a cell membrane is made from a double row of phospholipids, arranged with their hydrophobic "tails" facing each other. In this illustration of phospholipid structure, the head represents polar carboxyl heads of two fatty acids.



LIPIDS

Lipids are large, nonpolar organic molecules that do not dissolve in water. Lipid molecules have a higher ratio of carbon and hydrogen atoms to oxygen atoms than carbohydrates have. Lipids store energy efficiently. Lipid molecules have large numbers of carbon-hydrogen bonds, which store more energy than the carbon-oxygen bonds common in other organic compounds.

Fatty Acids

Fatty acids are unbranched carbon chains that make up most lipids. The model in Figure 3-14 shows that a fatty acid contains a long, straight 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 very different properties. The carboxyl end of the fatty-acid molecule is polar and is thus attracted to water molecules. Because of this attraction, the carboxyl end of the fatty-acid molecule is said to be **hydrophilic** (HIE-droh-FIL-ik), which means "water loving." 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, like palmitic acid, which is pictured in Figure 3-14, each carbon atom is covalently bonded to four atoms. The carbon atoms are in effect full, or "saturated." In contrast, you can see from the structural formula of a molecule of linoleic acid, shown in Figure 3-14, that the carbon atoms are not bonded to the maximum number of atoms that they can bond to. Instead, they have formed double bonds within the carbon chain. This type of fatty acid is said to be unsaturated.

Complex Lipids

Lipids are divided into categories according to their structure. Three classes of lipids important to living things contain fatty acids: triglycerides, phospholipids, and waxes. A **triglyceride** (trie-GLIS-uh-RIED) 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 solid at room temperature. Common dietary saturated triglycerides include shortening and animal fats. In contrast, unsaturated triglycerides are composed of unsaturated fatty acids and are usually liquid at room temperature. Unsaturated triglycerides are found primarily in plant seeds and fruits, where they serve as an energy and carbon source for sprouting plants.

Phospholipids have two, rather than three, fatty acids joined by a molecule of glycerol. As shown in Figure 3-15, the cell membrane is composed of two layers of phospholipids, which are referred to as 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. This bilayer arrangement of molecules produces a stable and effective barrier for a cell.

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

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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 cells and other cells to function normally.

H

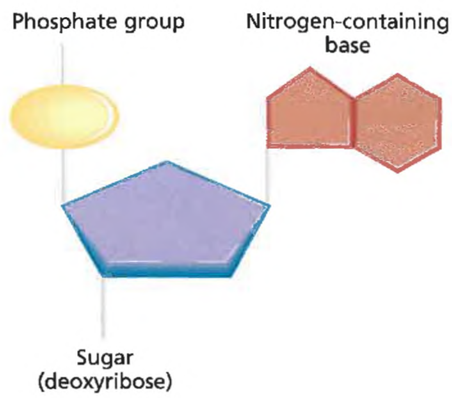
NUCLEIC ACIDS

Nucleic acids are very large and complex organic molecules that store important information in the cell. Just as computers use a binary system of zeros and ones to store information, nucleic acids use a system of four compounds to store hereditary information. A sequence of the four compounds arranged in a certain order acts as a code for the genetic instructions of the cell.

Deoxyribonucleic acid, or DNA, contains information that is essential for almost all cell activities, including cell division. **Ribonucleic** (RIE-boh-noo-KLEE-ik) **acid,** or **RNA,** stores and transfers information that is essential for the manufacturing of proteins. Both DNA and RNA are polymers, composed of thousands of linked monomers called **nucleotides** (NOO-klee-uh-TIEDS). As shown in Figure 3-16, each nucleotide is made of three main components: a phosphate group, a five-carbon sugar, and a ring-shaped nitrogen base. You will learn more about these important compounds in Chapter 10.

FIGURE 3-16

A nucleotide consists of a phosphate group, a five-carbon sugar, and a ring-shaped nitrogen base. DNA and RNA are very large molecules formed from thousands of nucleotides strung together in a chain.



SECTION 3-3 REVIEW

1. Define *monosaccharide, disaccharide,* and *polysaccharide.*
2. Describe the structure of amino acids and proteins.
3. Explain the relationship between an enzyme and its substrate.
4. How do the two ends of a fatty acid differ?
5. Name the two types of nucleic acids, and describe their functions.
6. CRITICAL THINKING High temperatures can weaken bonds between different parts of a protein molecule, thus changing its shape. How might this change alter the effectiveness of an enzyme?

Research Notes

The Structure of Insulin

Insulin is a hormone secreted by cells within the pancreas. It is essential in regulating the metabolism of carbohydrates and fats in the body. People with the disorder diabetes mellitus do not produce enough insulin. Some diabetes patients must take insulin injections to maintain normal metabolism.

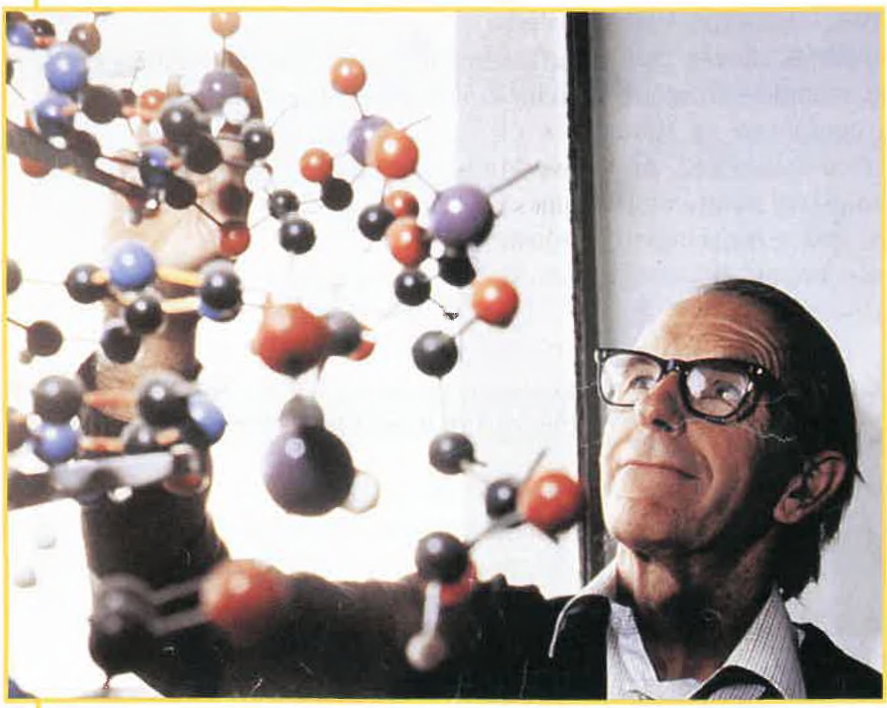
In 1943, the British biochemist Frederick Sanger set out to analyze the insulin molecule. He was interested in proteins, and he chose insulin as the subject of his research mainly because, as he put it, "It was the only protein you could buy in pure form over the counter." He knew that an understanding of the structure of insulin could have important implications for medical practice. He spent the next 12 years studying the structure of insulin.

Biochemists already knew that proteins consist of combinations of 20 different amino acids linked together in chains. They also knew how to calculate the proportion of each amino acid in a given protein. What they did not know was the order in which the amino acids are linked in a specific protein. They correctly believed that the sequence of amino acids in a protein is crucial to the protein's function. Sanger's goal was to determine the amino acid sequence of insulin, and to do so, he had to develop new laboratory techniques.

Sanger began with a strategy familiar to chemists. He broke the insulin molecule into pieces. After splitting the chains of amino acids into short fragments, Sanger came to understand how they fit together. In his quest to determine the structure of insulin, he devised a new way to label the ends of a protein fragment.

Sanger learned that insulin is made up of two linked chains, one containing 30 amino acids and the other containing 21. He looked for fragments with overlapping sequences, which helped him discover how each chain was put together. By 1952, he had learned the amino acid sequences of both chains, but he still needed to understand how the two chains were linked to make up one insulin molecule. Three years later, Sanger reached his goal of identifying the molecular structure of insulin.

Sanger's work with insulin established him as the leader in his field, and in 1958 he received a Nobel Prize in chemistry. By demonstrating that each protein has a unique structure and likewise a unique sequence of amino acids, Sanger paved the way for the development of a technique that enabled the synthesis of insulin in the laboratory. In 1980, he received a second Nobel Prize in chemistry for his work in developing techniques for determining the sequence of nucleotides in molecules of DNA and RNA. Sanger is one of only four people to ever be awarded two Nobel Prizes.



Frederick Sanger was the first scientist to determine the sequence of amino acids in a protein.

CHAPTER 3 REVIEW

SUMMARY/VOCABULARY

3-1

- Water is a polar molecule in which the electrons are unevenly shared between the hydrogen and oxygen atoms.
- Because of its polar nature, water is effective in dissolving other substances to form solutions.
- Hydrogen bonding is responsible for the cohesion and capillarity that water molecules display.
- Water can absorb a large amount of thermal energy before its own temperature begins to rise.

Vocabulary

adhesion (51)
capillarity (51)
cohesion (51)
hydrogen bond (50)
polar (50)

3-2

- An organic compound contains carbon that is covalently bonded both to other carbon atoms and often to atoms of other elements, including oxygen, hydrogen, and nitrogen.
- A carbon atom forms four covalent bonds with other atoms. Carbon atoms can bond with one another to form straight chains, branched chains, or rings.
- Simple molecules, known as monomers, bond to one another to form complex molecules called polymers. Monomers are joined to form polymers in a condensation reaction. Polymers are broken down into monomers during hydrolysis.
- An alcohol is an organic compound that contains a hydroxyl group, OH^-, attached to one of its carbon atoms.
- Adenosine triphosphate (ATP) makes energy available to a cell.

Vocabulary

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

3-3

- A carbohydrate is an organic compound composed of carbon, hydrogen, and oxygen atoms in a ratio of about two hydrogen atoms to one oxygen atom. A monomer of a carbohydrate is called a monosaccharide.
- A double sugar is called a disaccharide. A complex sugar made of many monosaccharides is called a polysaccharide.
- A protein is an organic molecule that is formed from amino acids. An amino acid consists of a central carbon atom to which four functional groups are attached.
- Amino acids are joined by peptide bonds. A long chain of amino acids is called a polypeptide.
- Enzymes are catalysts that act in living things. Enzyme action can be explained by the lock-and-key model. Most enzymes are proteins.
- Most lipids contain fatty acids, organic molecules that have a hydrophilic end and a hydrophobic end.
- Unsaturated lipids have one or more pairs of carbon atoms joined by double bonds. Saturated lipids have no double bonds between their carbon atoms.
- Lipids store more energy than the other types of organic molecules.
- Nucleic acids are organic molecules that store genetic information in the cell.

Vocabulary

amino acid (56)
carbohydrate (55)
dipeptide (57)
disaccharide (56)
fatty acid (58)
hydrophilic (58)
hydrophobic (58)
isomer (55)
lipid (58)
monosaccharide (55)
nucleic acid (59)
nucleotide (59)
peptide bond (57)
phospholipid (58)
polypeptide (57)
polysaccharide (56)
protein (56)
ribonucleic acid (RNA) (59)
steroid (59)
substrate (57)
triglyceride (58)
wax (59)

REVIEW

Vocabulary

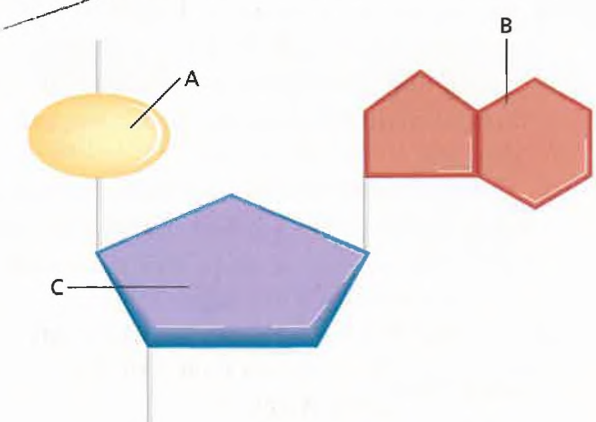
1. Explain the relationship between amino acids, peptide bonds, and proteins.
2. How are the structures of monosaccharides, disaccharides, and polysaccharides related to each other?
3. Explain the relationship between a polypeptide and a peptide bond.
4. What is the difference between a hydrophilic substance and a hydrophobic substance?
5. Why is the structure of the cell membrane referred to as a bilayer?

Multiple Choice

6. Water helps keep the temperature of living things (a) high (b) low (c) below the freezing point (d) stable.
7. The distinguishing feature of a molecule of a polar compound is its (a) even distribution of electrical charge (b) uneven distribution of electrical charge (c) even temperature (d) uneven temperature.
8. The element that readily bonds to itself, forming long chains and rings, is (a) hydrogen (b) nitrogen (c) carbon (d) oxygen.
9. Plants store glucose in (a) a polysaccharide called starch (b) long proteins (c) complex lipid molecules called triglycerides (d) simple sugar molecules.
10. A very strong structural molecule in plants that is formed by hydrogen bonding between chains of glucose molecules is (a) starch (b) wax (c) cellulose (d) glycogen.
11. When two amino acids bond, (a) water is taken in by the product (b) hydrolysis occurs (c) a dipeptide is formed through a condensation reaction (d) a triglyceride is formed.
12. Lipids are distinguished from other organic molecules because they (a) contain carbon, hydrogen, and oxygen in a ratio of 1:2:1 (b) do not dissolve in water (c) dissolve easily in water (d) form large protein molecules.
13. Steroids differ from other lipid polymers in that steroids (a) do not occur in varied substances (b) are not hydrophilic (c) are not hydrophobic (d) are not composed of fatty-acid monomers.
14. Most enzymes are (a) lipids (b) phospholipids (c) proteins (d) carbohydrates.
15. A compound that stores hereditary information is (a) ATP (b) alcohol (c) DNA (d) protein.

Short Answer

16. Label the parts of the nucleotide below.



17. What are isomers?
18. What properties do alcohols and water share?
19. Compare and contrast a condensation reaction with a hydrolysis reaction.
20. Use a diagram to show how enzymes work.
21. How does the carboxyl end of the fatty-acid molecule differ from the hydrocarbon end of the molecule?
22. Compare and contrast the structures of triglycerides, phospholipids, and steroids. Which type of lipid is structurally unlike the other two?
23. What role does the compound ATP play in cellular activities?
24. What is an important characteristic of waxes, and why is this valuable to living things?
25. What structural role do phospholipids play in cells?

CRITICAL THINKING

1. 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?
2. The surface tension of water at room temperature is so great that you can actually "float" a small needle on the surface of water. (The needle doesn't truly float—it is denser than water. It is held in place by the force of hydrogen bonding between water molecules lying below and around the needle.) If the water were heated, what would happen to the needle and why?
3. Starch easily dissolves in water. Cellulose does not. Both substances, however, consist of chains of glucose molecules. What structural difference between starch and cellulose accounts for this different behavior in water?
4. Triglycerides in animals' bodies are usually solid fats, and those in plants are usually oils. However, many animals living in the Arctic and Antarctic have a greater number of triglycerides that are oils than do other animals. What advantage would the storage of body fat as oil instead of solid fat be to animals that live in freezing climates?
5. The specific heat of a substance is the amount of heat that must be added to 1 g of the substance to raise its temperature 1°C. Specific heat is measured in calories. Use the table to answer the following questions.
   a. What substance can absorb the greatest amount of heat before its own temperature rises?
   b. What do the two substances with the lowest specific heat values have in common?
   c. What property of ethanol might account for its relatively high specific heat?
   d. Which would be a better conductor of heat: iron or glass?
   e. What practical use would a substance with a very high specific heat have?

Specific Heats of Common Substances

Substance	Specific heat (cal)
Lead	0.03
Iron	0.10
Glass	0.20
Ethanol	0.60
Water	1.00
Liquid ammonia	1.23

EXTENSION

1. Read "Alien Haven" in *New Scientist*, September 18, 1999, on page 32, and answer the following questions: What are the "Goldilocks criteria" for a planet to be ideal for life? What is the "habitable zone," where a planet that can support life is most likely to be found?
2. Cut fibrous meat into four 1 in. cubes. Sprinkle three of the cubes with equal amounts of meat tenderizer, which contains a protein-splitting enzyme called papain. Place one cube in the refrigerator, leave one at room temperature, and place the other in an incubator at 32°C. For the fourth cube, place the same amount of meat tenderizer and a few tablespoons of water in a container, and boil the mixture for three minutes. (Do not allow the mixture to boil dry. Add water, tablespoon by tablespoon, as needed.) Pour the boiled mixture on the meat. After three hours, observe the texture of all four meat cubes. What do you conclude about the effect of temperature on the enzyme in meat tenderizer? Express your results as a graph showing temperature and the apparent level of activity of the enzyme.

CHAPTER 3 INVESTIGATION

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.*

PROCESS SKILLS

- experimenting
- observing
- measuring

MATERIALS

- lab apron
- safety goggles
- disposable gloves
- 1 L 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

Background

1. Carbohydrates, proteins, and lipids are nutrients that are essential to 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 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 determine the presence of some proteins (this procedure is called the biuret test). Sudan III is used to determine 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 like the one on the next page.

Test 1

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 1 L 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. Using a third dropping pipet, add 10 drops of distilled water to the

TABLE A 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					

"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

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

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 kind of macromolecules not tested for, and give one reason why they were not tested for.